# COMBUSTION



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Coal unloading plant, Puerto Nuevo Station, Buenos Aires

## COMBINATION WASTE HEAT AND PULVERIZED FUEL BOILER UNIT

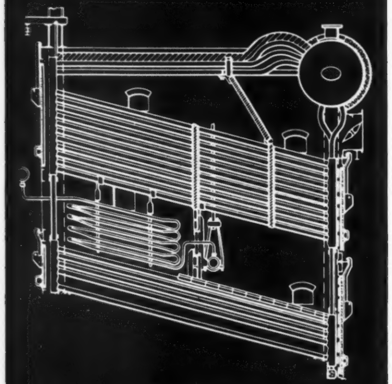
By W. H. D. Clark

## EMPIRICAL EQUATIONS

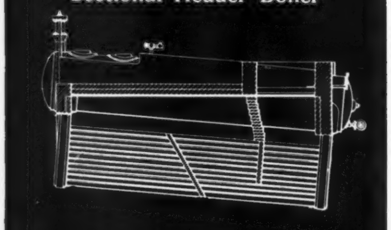
By D. S. Davis

Other Articles in This Issue By

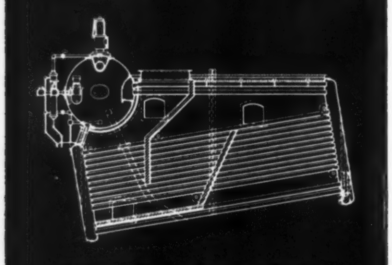
F. H. ROSENCRANTS • JOSEPH H. KEENAN • GEORGE RAMSEY



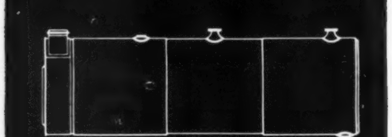
Walsh-Weidner
Sectional Header Boiler



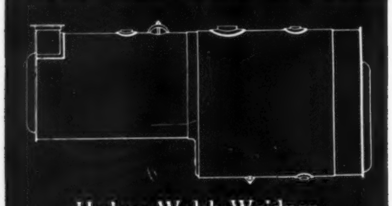
Heine Long-Drum Boiler



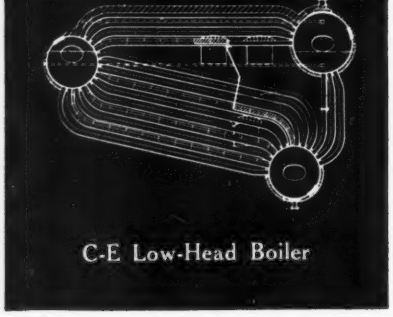
Heine Cross-Drum Boiler



Hedges-Walsh-Weidner h.r.t. Boiler



Hedges-Walsh-Weidner
Premier Semi-Portable Boiler



C-E Low-Head Boiler

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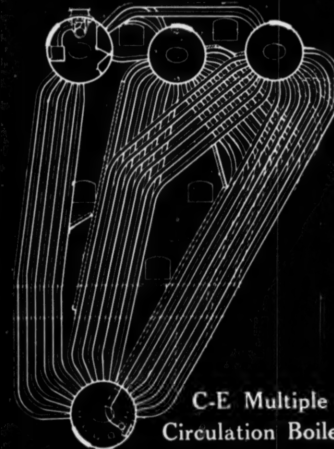
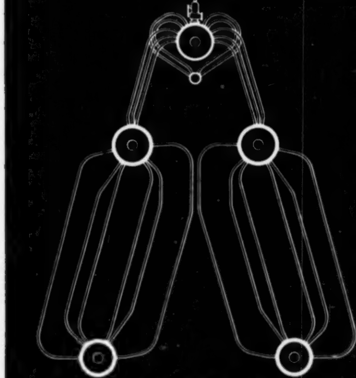
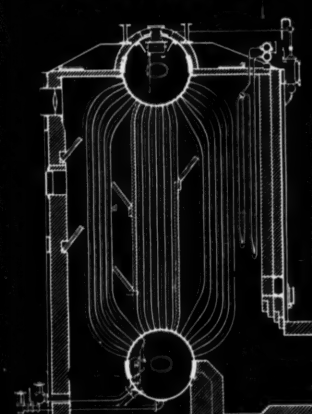


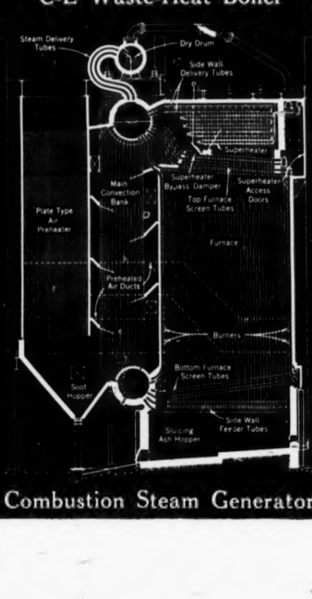
C-E Multiple
Circulation Boiler



Ladd Double Boiler



C-E Waste-Heat Boiler



Combustion Steam Generator

# COMBUSTION

VOLUME FOUR • NUMBER THREE

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### EDITORIALS



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|---|---|---|
| H. STUART ACHESON | CHARLES MCDONOUGH | F. H. ROSENCRANTS |
| *General Representative* | *Editor* | *Associate Editor* |

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# Commentary by Joseph H. Keenan

## The Joule-Thomson Effect

WHEN a perfect gas flows through a porous plug,* its temperature does not change. In itself this is a useless bit of information, the perfect gas, like the perfect man, being not of this world. When an actual gas flows through a porous plug, its temperature changes. In thermodynamics the change is known as the Joule-Thomson effect. Its magnitude is usually represented by the Joule-Thomson coefficient which is the rate of change of temperature with change in pressure during throttling. It can be determined experimentally by holding the pressure and temperature constant before a porous plug and measuring the temperature after the plug at several different pressures. These pressures and temperatures trace out a curve on a p, t chart. The slope of a straight edge laid tangent to this curve at any point is the Joule-Thomson coefficient at that pressure and temperature.

Along this throttling curve the enthalpy (or total heat) is constant, a familiar fact to those who have measured the quality of moist steam with a throttling calorimeter. The Joule-Thomson coefficient is thus the slope of a constant enthalpy line on a p, t chart.

If the Joule-Thomson coefficients are known over any range of pressures and temperatures, the line of constant enthalpy passing through any point may be traced out by a nose-following process which consists of proceeding in the direction indicated by the Joule-Thomson coefficients found at each new point as the line progresses. If by other means the enthalpy of one point on this line is determined, that value of enthalpy may be applied to every other point on the line. This method was first used by Dr. Davis in the development of his own experimental results.

Whatever degree of precision is attained in a Joule-Thomson experiment, with that precision we can find changes in temperature along a constant enthalpy line. If these changes are relatively small, as they usually are, it requires only a moderate experimental refinement to locate the line with accuracy. The Joule-Thomson coefficient is a measure of departure of the enthalpy line from constant temperature, which is also its departure from the perfect gas relationship, wherein lies its value in steam research.

Joule and Thomson found that most gases showed a fall in temperature across a throttle plug but that some few showed an actual rise in temperature. Since then it has been satisfactorily proven that practically all gases have a positive Joule-Thomson effect (falling temperature with falling pressure) at low pressures for all absolute temperatures less than about six times the critical temperature. Above that temperature, the so-called inversion point, the effect becomes negative. Hydrogen, for instance, with its very low critical temperature, shows a negative Joule-Thomson effect at room temperature. Superheated steam, on the other hand, shows a positive Joule-Thomson effect throughout the range of precise steam research, which must be extended to almost 7000 deg. fahr. before it includes the inversion point.

Dr. Davis became interested in the throttling experiment when he found that some early examples of it held the key to the first marked improvement over the Regnault formula for the enthalpy of saturated steam. Since then he has been the chief exponent of the Joule-Thomson method.

The earlier throttling experiments were of sufficient precision to revolutionize steam tables, but some improvement in technique was necessary before this type of measurement was ready to take its place in modern steam research. With Trueblood, Davis spent several years finding and stopping the sources of error. He found that immersing the throttle chamber in an oil bath held precisely at the temperature of the incoming steam does not eliminate heat leak. The steam that has flowed through the porous plug, being lower in temperature, by conduction cools the steam approaching the plug; and this in turn causes a still lower temperature on the low side which cools further the high side steam, which reminds one of how Baron Munchausen came down a rope by sliding to the end of it, cutting the long, now useless end of the upper part, which when tied to the lower end, brought him a good deal lower. In some such fashion the steam temperatures near Davis' porous plug descended toward Antarctic values. Of course, Antarctic temperatures were not reached, but the descent was stopped by a highly undesirable heat leak from the oil bath through the cold plug into the steam.

Trueblood's patient work produced a throttling apparatus in which the heat leak was small and determinable. It led directly to the Davis-Kleinschmidt measurements, the first fruits of the present American steam research program. Within the range covered by these measurements the coefficient for superheated steam is now clearly delineated, even to the details of its small variations at constant temperature. Knowledge in such detail leaves little uncertainty concerning the characteristics of superheated steam.

Joseph H. Keenan

**Stevens Institute of Technology**

* A porous plug is spoken of rather than an orifice or throttle valve to assure negligible velocity at exit. Adiabatic conditions—no heat transfer—are, of course, assumed.

# EDITORIAL

## The Lesson of the Coal Industry

EVERY business organization of any consequence should have at least one major executive whose principal responsibility should be the safeguarding of the future of the business. For the most part the tendency of management is to concentrate on the immediate problems of business to such an extent that developments both within and without the industry, which may change its whole complexion within a comparatively few years, are all too frequently unobserved.

No more glaring example of the consequences of this type of shortsightedness on the part of management exists today than the case of the coal industry. Writing in a recent issue of Black Diamond, Charles E. Stuart, notable mining engineer, says, "The American bituminous coal mining industry is today insolvent, except in spots, and these spots are few and far between." He further states that this state of affairs is not due to the current depression. The inception of the condition was manifest for some years prior to 1929 and grew progressively worse. Yet the factors which have brought about the present demoralized state of the industry were, or at least should have been, evident to alert-minded executives while they were still in the early stages of development. Group cooperation among the principal operators at that time would have prevented general increases in production capacity during a period when the competition of oil and gas was becoming increasingly serious, and would have directed the brains and resources of the industry along the lines of improving its product and the methods of its production and utilization. As Mr. Stuart sums up the present situation, "The coal mines of the United States are capable of producing more than twice their present output, and as a result of these conditions, vast natural resources are almost literally being given away yearly at the expense of labor, the producers and capital. . . ."

In these days of rapid and frequently revolutionary change, no business has the quality of permanency. Even such basic industries as the public utilities and railroads are subject to marked disturbance as witness the change in status of the latter in recent years due to the growth of aviation, and bus and truck transportation. Again, an industry that appears to be in the doldrums may be given new life by a single development such as that of rayon silk in the textile industry.

Merle Thorpe in his radio talks and in the pages of Nation's Business has given countless instances of developments and inventions which have radically altered the course of well-established businesses, and Floyd Parsons in his interesting articles in Gas-Age-Record and elsewhere has given us many glimpses of new things on the horizon which have large social and economic import to the future.

Progress is inevitable and those who are lacking in intelligent awareness of its manifestations are certain to find themselves outmoded and outdistanced as the procession passes by. Those organizations whose managements believe in and support research and insist upon an executive personnel which is qualified in vision as well as in business technique are the ones that are building for future as well as present success.

## The 1932 Power Show

ALL the signs would seem to indicate that the Tenth National Exposition of Power and Mechanical Engineering, to be held in Grand Central Palace, New York, the week of December 5th, will take place at a most opportune time.

For more than two years power equipment in hundreds of plants throughout the country has been maintained in use despite the degree of its obsolescence. Much of it is now incapable of meeting normal service demands and a great deal more of it, while still operative, is no longer efficient or economical.

In the period from which we are now emerging, many equipment manufacturers have taken advantage of the opportunity provided by "slow times" to improve their products. Research and development work has been carried on extensively, and, as a consequence, there has been decided improvement in practically all lines of equipment.

In the new order of competition, minimum production costs will be more than ever essential to profitable business, and minimum production costs are unattainable unless power and process steam are produced by equipment which reflects the best design and practice of *today.*

Industrial executives realize these things and want their engineers to be well-informed with respect to new and improved equipment. Operating engineers are equally desirous of doing their part in revamping and modernizing their plants.

The 1932 Power Show, held in conjunction with the annual convention of the American Society of Mechanical Engineers and presenting as it does a vast array of the latest designs of power equipment, affords to visiting engineers a unique opportunity to educate themselves and at the same time increase their value to their employers. Coming at the time it does, when so many indications point toward improved business in the immediate future, it should do much to accelerate activity in the power equipment field.

# The Design of Steam Generating Plants

## PART IV

### Factors Influencing the Selection of Combustion Equipment

By F. H. ROSENCRANTS, Consulting Engineer
Combustion Engineering Corporation, New York

**We take much pleasure in publishing this installment in the series by Mr. Rosencrants because we believe it is one of the most valuable discussions of the broad factors affecting and limiting the selection of combustion equipment that has come to our attention. The factors given the most consideration are fuel characteristics and size of unit, and in connection with both the author gives us the benefit of his own very wide experience in views that are definitely expressed yet properly qualified where he deems such qualification necessary. As he expresses it in the concluding paragraph, no general statements can be made which will serve as an infallible guide to the correct solution of individual problems. The factors affecting each case are so many and so varied that general principles should be considered only in the light of judgment that is based on extensive experience.**

VARIATIONS in characteristics of coal deposits of the United States embrace the complete range from peat to graphitic anthracite and includes all intervening classifications. The result has been the intensive development of a wide range of combustion equipment including:

- Pulverized Fuel Equipment
- Underfeed Stokers
- Traveling Grate Stokers
- Overfeed Stokers

Each of these classifications includes a variety of designs by individual and competitive manufacturers. Each class, with its variations, is applicable to a wide range of fuels and overlaps the fields of other classes. In fact, any one class of equipment can be adapted to burn any class of coal fuel at some rate and at some efficiency. The purchaser in his problem of selecting the best equipment for the job, is therefore placed in a position demanding a high degree of discrimination.

*Technical Characteristics of the Fuel*

Nothing is so valuable in the selection of combustion equipment as a first-hand knowledge of the manner in which the coal under consideration behaves in the furnace and the limitations actually experienced when burning it with different types of firing apparatus.

To an engineer of even a very limited experience, the mere classification of the fuel, i.e., whether it is coke breeze, anthracite coal, bituminous coal or lignite, suggests limitations of any specific class of equipment and narrows the field of equipment selection. A further sub-division, such as, eastern bituminous, Pittsburgh bituminous, and mid-west bituminous, suggests still further equipment limitations and still further narrows the field of selection. Specific designation by trade name, location and seam, name of mine, etc., may so bring the coal within the knowledge of the engineer of broad experience that he is in position to immediately recommend equipment best suited to its use under the specified operating conditions.

In giving consideration to suitability of combustion equipment, even the most experienced engineer thinks either consciously or sub-consciously in terms of—

- Caking or free burning characteristics
- Moisture content
- Ash Content
- Volatile content
- Fusing temperature of the ash
- Screen analysis
- Heating value
- Grindability
- Etc.,

on the part of the fuel in relation to—

Combustion rate per sq. ft. of grate surface
Heat liberation per cu. ft. of furnace
Necessity for fuel bed agitation
Ease or difficulty of ignition
Carbon loss in fly ash
Slagging and clinkering
Power and maintenance
Etc.,

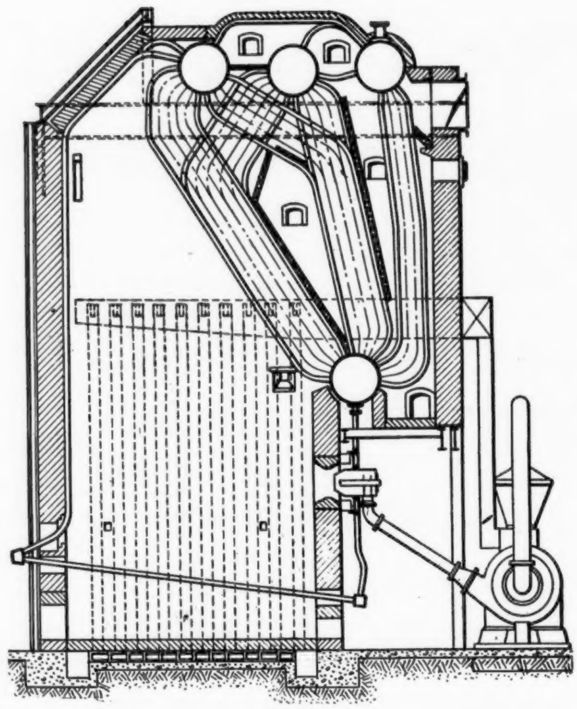
Unless he possesses a very intimate and positive knowledge of the coal in contemplation, he will require, before making a final committment, and in confirmation of the knowledge already at his command, a proximate analysis showing moisture, volatile, fixed carbon, ash and sulphur content; also the fusion temperature of the ash and a heating value determination.

Technical knowledge of a fuel covering the above enumerated points will in itself serve as a reasonably accurate guide in most cases as to the particular type or types of equipment most suitable to its use. In the absence of any knowledge based on experience with the particular coal in question, however, estimates of capacity limits, furnace losses and performance generally will be uncertain until established in actual operation.

*Limitations of Equipment as Fixed by Fuel Supply*

Pulverized fuel firing, the most recent system of firing to be developed on a commercial scale, covers a wider range of adaptability than any other class of combustion equipment. Even so it is not universally applicable.

Coke (coal by-product) should rarely and probably never be considered as a fuel for pulverized fuel firing. The energy requirements and maintenance charges involved in the pulverizing process will, in nearly if not in every case, exceed economic limits. This condition arises, first, from the abnormal fineness to which coke must be ground to secure an approach to satisfactory combustion conditions, and second, to the highly abrasive character of the material and the consequent rapid wear on pulverizing equipment. Furthermore, coke is not a satisfactory fuel to burn in pulverized form. The absence of volatile matter makes it very difficult to ignite, and as a result satisfactory furnace conditions upon starting up are difficult to establish and also to maintain, particularly at low ratings. Carbon losses in the fly ash, even with very fine grinding, will be high with corresponding loss in efficiency. More satisfactory results will invariably be attained with a properly designed traveling grate stoker and furnace installation.



**Direct fired boiler with horizontal burner. (Burner may be designed for combination firing of coal, oil and gas.)**

**Large double boiler arranged for vertical firing from both sides. Bin and feeder system.**

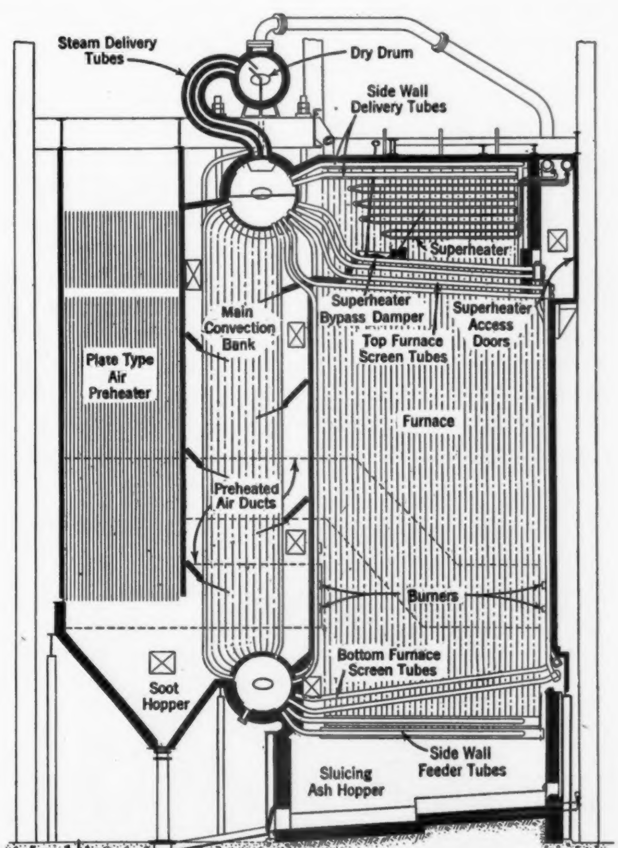
Anthracite coal should seldom, and for the same reasons as applying to coke, be considered as a suitable fuel for pulverized fuel firing. Some installations are in successful operation, but with the exception of those instances in which the fuel before pulverizing is very fine in size, more satisfactory performance will be secured with a suitably designed traveling grate stoker and furnace installation.

All other coals from semi-anthracite down to and including lignite, are entirely suitable for and are being fired extensively in pulverized form. For boilers of extremely high capacity, say 500,000 lb. of steam per hour and above, pulverized fuel firing is practically without competition simply because of the fact that stoker equipment is not established for ratings of such magnitude. Whether or not

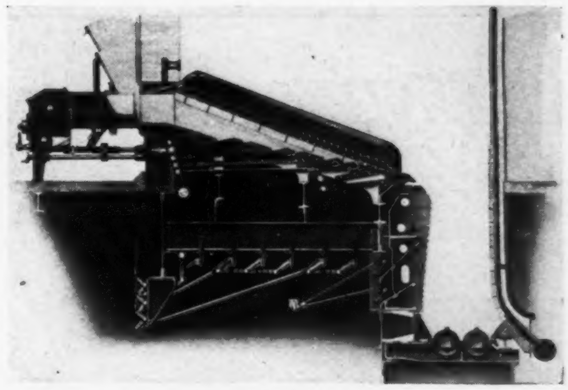
stokers can be developed along lines such as to make them attractive in competition with pulverized fuel in this range of capacity, is a matter for speculation. As we descend the scale of capacities, pulverized fuel comes more and more into competition with traveling grate and retort type stokers, either of which in specific cases may be selected in preference to pulverized fuel for good and sufficient reasons.

In the stoker field the superior merit of the underfeed stoker, both multiple and single retort type, for low ash coals having strong caking characteristics, is undisputed. It will not, however, satisfactorily handle coke breeze, anthracite or lignite and its advantages diminish and finally disappear as the caking tendency of the coal diminishes and the ash content increases and becomes more fusible. Coke, anthracite and lignite are difficult to ignite and would require an arch over the front end of the stoker to maintain ignition of the incoming fuel. None of these fuels has any tendency to cake when heated and all burn better if left undisturbed.

The fuel bed of strongly caking coal forms into a solid mass through which it is impossible to obtain a flow of air in sufficient volume to give a satisfactory combustion rate. To obtain volume of air flow and uniformity of distribution it is necessary to continually agitate the fuel bed and keep it broken up until the volatile matter is driven off. Forced draft and a thick fuel bed are essential.




**Steam generator arranged for tangential firing from the four corners.**



**Multiple retort type stoker for medium-size and large boilers.**

The retort type stoker has been developed to meet these requirements and it is in almost universal use in stoker-fired plants using coals from the Appalachian region. Coals from along the eastern edge of this region, running through the States of Pennsylvania, Maryland and West Virginia, will not burn satisfactorily on any other type of stoker.

These coals all have strong caking tendencies. The proximate analysis runs:

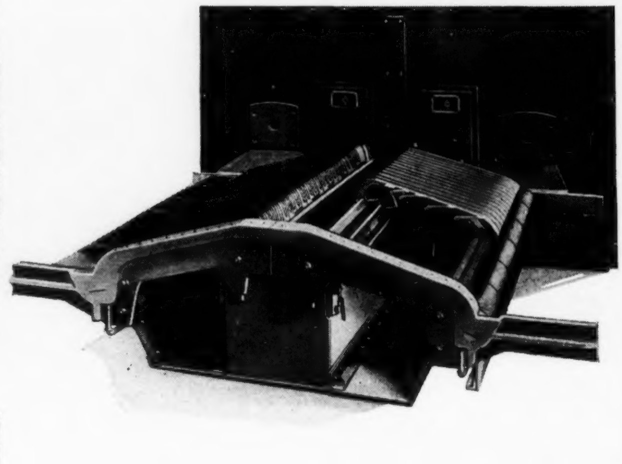
| | |
|---|---|
| Volatile | 16 to 23 per cent |
| Fixed Carbon | 67 to 76 per cent |
| Ash | 3 to 10 per cent |
| Moisture | 2 to 5 per cent |
| Heat Value | 14,000 to 15,000 B.t.u. per lb. |

The retort type of stoker has been applied with some degree of success to the burning of non-caking or free-burning coal with high ash content. In doing so, however, it is over-lapping the field for which the traveling grate stoker was primarily designed. Free-burning coals do not need agitation and in fact burn better if the fuel bed is undisturbed. Agitation aggravates the formation of large clinkers which incorporate within their mass large percentages of carbon and which are difficult to remove from the furnace.

The traveling grate stoker in some form is adapted to all forms of solid fuel including coke breeze, anthracite, bituminous coal and lignite. It will not, however, satisfactorily handle the coals which cake into large solid masses when heated. Such coals include a large part of the production from the Appalachian region. Some of the coals from this region will burn satisfactorily on traveling grates but careful investigation should be made before deciding on a traveling grate for any coal from this region.

Insofar as bituminous coals are concerned, the traveling grate finds its great field of application in connection with the coals of the middle west, including the States of Indiana, Illinois, Iowa, Missouri and Kansas. It also handles the subbituminous coal of Colorado and the lignites of Texas, North Dakota and Montana.

A certain minimum limit of 7 to 10 per cent of ash as a protection to the grate surface was, until the advent of rear arch settings, considered essential to successful operation with traveling grates.



**Underfeed stoker for small and medium-size boilers.**

With the rear arch setting, however, the rear end of the stoker is shielded from the radiant heat of the furnace and over-heating is prevented. This type of setting is gaining popularity and except in the case of very short stokers promises to supersede the old front arch construction for all fuels from coke breeze to lignite.

With the front arch, ignition of the incoming fuel was effected by the radiant heat from the highly incandescent arch. With the rear arch setting, the heat for drying and igniting the incoming fuel comes from the furnace flame as it issues from under the arch. The incandescence of the arch itself ceases to be a factor and the arch may be of water cooled construction if desired. To effectively mix the volatile gases distilled from the incoming fuel with the gases issuing from under the arch, overfire air in the form of jets is desirable; in fact is essential to obtain the best results with high volatile coals.

The overfeed stoker has a limited field of application in connection with boilers of small and medium capacity operating at moderate ratings. Its mechanism provides a small amount of agitation which enables it to burn coals having some caking tendencies and also free-burning coals. It is primarily designed for natural draft and operates with a thin fuel bed compared with the retort type stoker. The agitation of the fuel bed aggravates clinker formation with coals having a high ash content of low fusion temperature. With moderate combustion rates of 20 to 25 lb. of coal per square foot, per hour, however, overfeed stokers give a satisfactory performance and meet a considerable industrial demand.

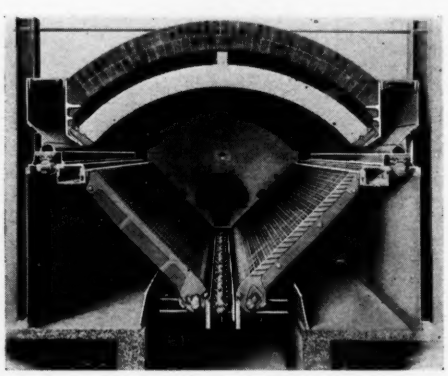
### *Influence of Capacity on Equipment Selection*

For units of extreme ratings, about 350,000 lb. per hr. and up, pulverized fuel should receive foremost consideration. Units producing over 1,000,000 lb. of steam per hr. with pulverized fuel firing are now operating. Larger units up to the limit of size that it is possible to build a boiler may be pulverized-fuel fired without encountering any new problems. The absence of machinery associated directly with the boiler makes this possible. Mills, pulverized coal feeding and burning equipment may be supplied in the required number of standard units to give the capacity.

Manufacturers of retort type stokers claim to be prepared to meet demands for units of over 350,000 lb. per hr. capacity, but thus far such units are not established in service and their development along acceptable lines is for the present a matter of speculation. Of course, this does not apply to units where the boiler surface can be so distributed as to permit the installation of two stokers in a single furnace. Where such arrangements are practicable, somewhat higher capacities can be obtained with stoker firing.

Boiler units and furnaces increase in capacity in proportion to the cube of their linear dimensions. The grate surface of a stoker unit increases only with the square feet of plant area. For the stoker capacity to keep pace with the boiler capacity as the size is increased means that the combustion rate on the stoker must be progressively increased.

For either retort type or traveling grate stokers,



**Overfeed stoker for small boiler using light caking or free burning coal.**

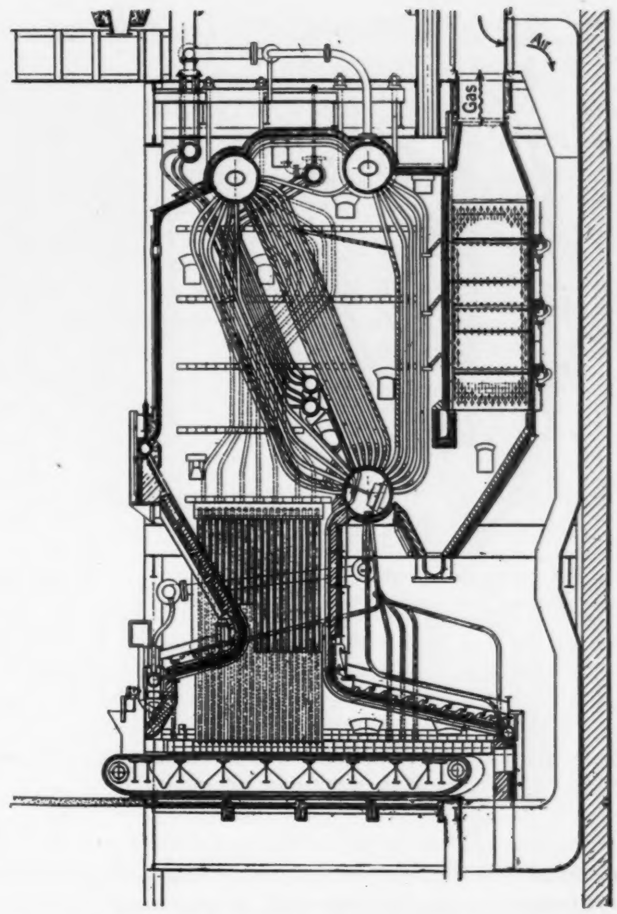
with the most suitable qualities of coal, a combustion rate of 45 to 50 lb. per sq. ft. approaches the limit for comfortable operation. Sixty pounds, and under the most favorable conditions, even 70 lb. of coal per sq. ft. is a possibility with expert nursing. At a rate of about 40 lb. per sq. ft. the cinder blown from the fire-bed and up through the boiler is moderate. At about this point, however, the rate of increase becomes rapid and continues with an accelerated pace until at rates much in excess of 55 lb. it is prohibitive. Extreme rates are not popular and are seldom advisable.

Increasing the width of a retort type of stoker introduces no new operating difficulties. Increasing the length, however, intensifies the problem of distribution. With extremely long stokers a considerable period of time is likely to be absorbed in developing the proper technique in following up adjustments of rams, pushers, clinker grinders, and air distribution to meet the demands of varying loads. The demands on operating technique are certainly increased as the retort type stoker becomes larger and longer, as the rate of combustion per square foot increases and as the quality of the coal becomes poorer. All of these factors react against this type of combustion equipment for capacities in excess of 350,000 lb. per hr. for the best grades of coal. For poorer grades of coal, lower capacity limits apply.

Traveling grate stokers have not thus far been built in this country for steam capacities much in excess of 200,000 lb. per hr. A 250,000 lb. unit may be considered as a present limit which can be fired with traveling grates without further development in design and construction features.

The operating problems with large traveling grates are but little increased over those encountered with smaller units. Fuel bed thickness, stoker speed and air distribution are the major variables. The ash discharge is continuous and automatic. With a reasonable amount of experience and a well designed installation, a proper operating technique will be developed in a short period of time.

With a descent in the scale of capacities the

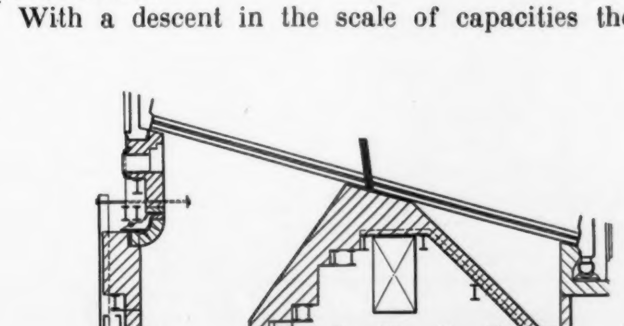



**Chain grate stoker with completely water-cooled, combination-arch-type furnace designed for bituminous free-burning and light-caking coals.**

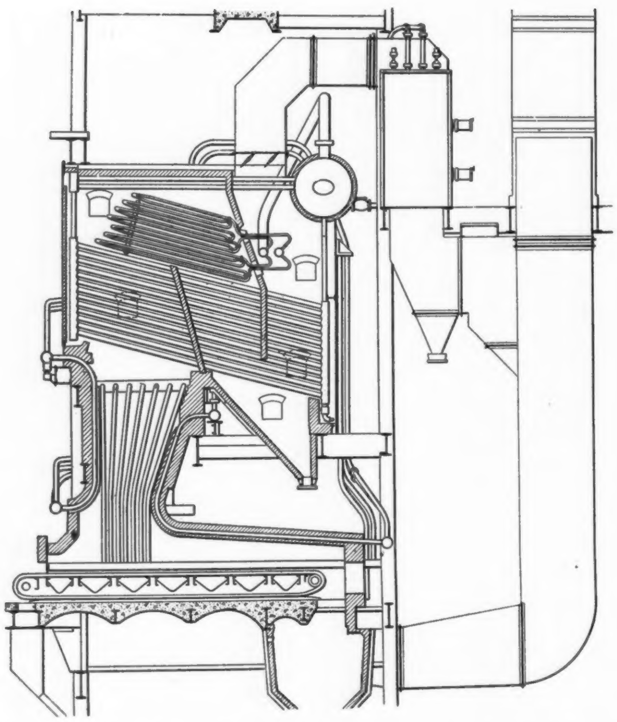
economic advantages of pulverized fuel firing diminish and finally disappear in favor of stokers. The exact point of equilibrium between the two depends on many circumstances such as character and price of fuel, load factor, etc. At 75,000 lb. steam per hr. and below, however, the economic advantages will normally be in favor of stoker firing. Special fuel or unusual load conditions, variable character of fuels available, etc., may, however, dictate the desirability of pulverized fuel firing for much lower capacities.

The chief element of disadvantage of pulverized fuel on the small and medium-size boilers is most likely to be that of cost. For best results, both economically and from an operating point of view, pulverized fuel furnaces should be water-cooled. In the absence of water cooling, the furnace should be made large or be operated with high excess air as a means of limiting furnace maintenance. This is particularly true with coal having a high ash content which fuses at low temperature and for a plant which contemplates high load factor, 24-hr.-per-day operation. For a low load factor plant on 8 to 12-hr.-per-day service, the precaution is less important.

Water cooling of the furnaces, while highly desirable and particularly so if high-load-factor, 24-hr.-per-day operation is contemplated, is not so essential for medium and small-size stoker-



**Traveling grate stoker with long rear-arch-type furnace designed for lignite.**



**Chain grate stoker with water-cooled, rear-arch-type furnace designed for small sizes of anthracite.**

fired jobs. If a modest rate of combustion per square foot of grate surface is adopted, the furnace temperature and the amount of coal dust and ash entrained in the furnace gases will be such that the consequent erosion of brickwork will be within reasonable limits. So designed, the cost of the stoker-fired job and efficiencies attainable will in many cases give overall economic and operating results which cannot be equalled with pulverized fuel firing.

For the range from 75,000 to 350,000 lb. per hr., above which pulverized fuel firing is favored and below which stoker firing is favored, there lies a wide and popular range of unit capacities. Whether in any specific case a unit should be stoker or pulverized fuel fired will depend upon the particular set of circumstances surrounding the case. Personal preference is no small factor and if the decision based on economic considerations is at all close, slight differences in the basic assumptions of such factors as first cost, operating efficiencies, price of fuel, load factor, rate of fixed charges, etc., can be made to make the final answer just whatever is desired.

### *Influence of a Variable Fuel Supply*

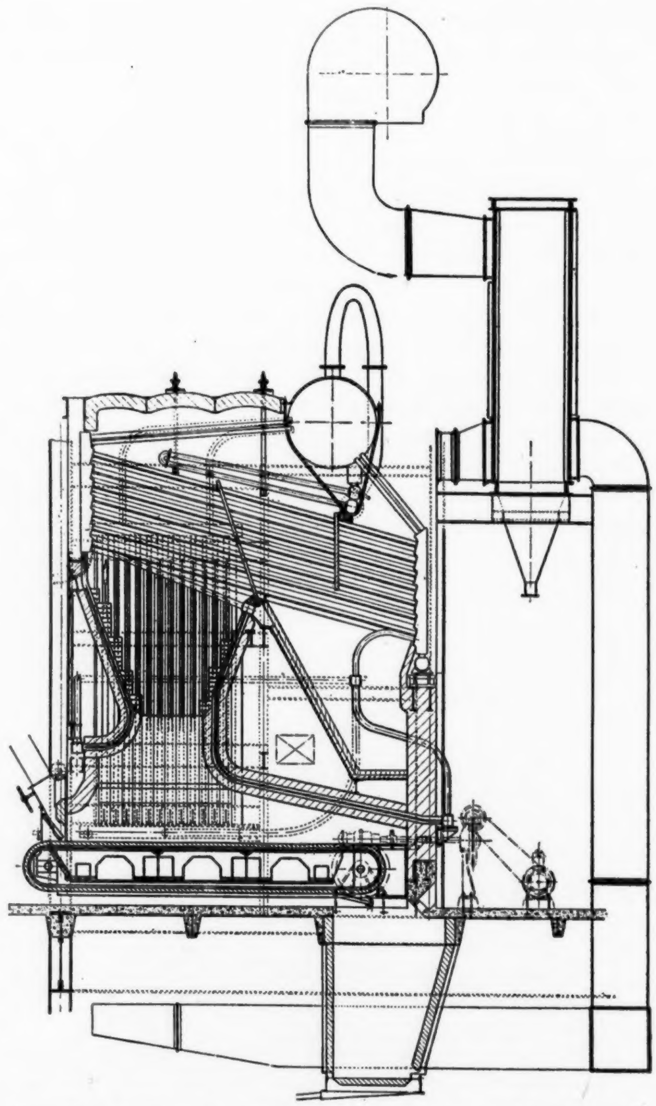
In the ability to utilize coals of widely varying characteristics indiscriminately in the same furnace and without materially altering the routine of operation lies a major advantage of pulverized fuel firing. Such flexibility is undisputed. It places a plant in a most advantageous position from a fuel-purchasing point of view if it is so placed that coals of varying characteristics are equally available.

Stoker equipment, though adaptable to the use of a considerable range of coal characteristics, cannot make the change from one to the other indiscriminately. Each coal will require a certain operating technique and it is extremely unlikely that the available coals of varying characteristics will be equally satisfactory.

If the idea of variation of fuel characteristics is extended to cover combinations of coal and oil, coal and gas or coal, oil and gas, then pulverized fuel firing for the coal has all the advantages in its favor over stokers—even for small-size units.

### *The Fly Ash Problem*

The fly ash problem is often a factor adversely affecting the choice of pulverized fuel firing in preference to stoker. The importance of this factor will depend upon the location of plant, with reference to its immediate surroundings, upon its capacity and upon the amount of ash in the fuel. With small and medium-size plants located in an industrial neighborhood the problem is not usually serious and no special precautions need be taken. For the other extreme, however, of a large plant located contiguous to a high-class residential neighbor-



**Traveling grate stoker with water-cooled, combination-arch-type furnace designed for coke breeze.**

hood or a shopping center, the removal of fly ash from the flue gases must be provided for. In many cases all that is necessary is a good high stack. In others, a comparatively simple and inexpensive dust removal equipment for partial elimination of the dust will serve to reduce the fly ash within permissible limits. In others, substantially complete elimination requiring an expensive installation will be demanded.

The problem of fly ash removal is not peculiar to pulverized fuel as similar requirements will be placed on stoker fired installations. The fly ash from stokered plants, however, is invariably less in quantity and though it is of a more objectionable character due to its coarseness, it is more easily and less expensively removed. If combustion rates per square foot of grate surface are maintained at a low figure many stoker installations will pass requirements with no special equipment for dust removal whereas pulverized fuel firing would require such apparatus.

In conclusion it should be emphasized that no general statement is possible which will serve as an infallible guide to the correct selection and detail proportioning and construction of combustion equipment. There is no substitute for good judgment based on extensive experience. Furthermore, the final success of an installation depends as much upon the perfection of detail in design and construction as upon the wisdom in the selection of the general type of equipment. Both are essential.

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## Worthington Consolidates Cincinnati With Buffalo Plant

Worthington Pump and Machinery Corporation, with executive offices at 2 Park Avenue, New York, and general offices at its Harrison, N. J., Works, has announced the decision to transfer and consolidate the designing, engineering and manufacturing activities formerly carried on at its Cincinnati, Ohio, Works, with those of its Buffalo, N. Y., manufacturing plant.

During the past five years it has been the corporation's policy to foster the interchange of work between its various manufacturing establishments and to further this coordination by an interchange of key men. In order to fully conserve its position, skill and experience, and to assure satisfactory service to its customers, necessary members of the Cincinnati Works organization are being transferred to Buffalo. Sufficient time is being provided for the move so that service to customers will be uninterrupted.

For the present, the Cincinnati plant equipment will remain intact. This move in no way affects Worthington's Cincinnati District Sales Office, which is under the management of Mr. Earl Vinnedge.

## Edison Company to Celebrate Fiftieth Anniversary First Permanent Commercial Electric-Lighting System

Frank W. Smith, President of the New York Edison Company, has announced that plans are being made to celebrate the fiftieth anniversary of Thomas A. Edison's first permanent commercial electric lighting system, the pioneer of the present globe-encircling electric light and power industry. Edison's pioneer plant was the old Pearl Street Generating Station, at 255-257 Pearl Street, in lower Manhattan, which was placed in commercial operation at 3 p. m., Monday, September 4, 1882.

The celebration will be held on two dates—September 4 and 12. The September 4 program, which will come on Sunday, will be a brief ceremony held at 3 p. m., at the site of the old station. The second celebration will be a dinner at the Waldorf-Astoria, to which representatives of the electrical industry in its various branches, and of civic, scientific and engineering bodies are being invited.

Mr. Smith pointed out that Edison's first station opened with fifty-nine customers, and with a generating plant of six dynamos, each of which could light from 1200 to 1750 sixteen candlepower incandescent lamps. Today through the electric companies affiliated with the Consolidated Gas System, he said, there are more than two million consumers supplied, with a total generating capacity in the various plants which represents power to light more than 47 million 50-watt lamps.

By 1882 the Edison Electric Illuminating Company had 78 employees on the payroll, as contrasted with more than 31,000 among the affiliated electric companies at this date.

Today the industry serves more than 24 million customers in this country alone. The pioneer company had a capitalization of $1,000,000. Today about 13 billion dollars is invested in the industry in the United States. The original 750 hp. capacity of the Pearl Street Station has grown to 46,000,000 hp. in the United States.

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**The Mercon Regulator Company,** Chicago, announces the appointment of the following new district representatives: The Laney Company, Tulsa, Okla.; Ambler & Riter, Inc., Denver, Colo.; L. J. Riter, Salt Lake City, Utah; Hughes Machinery Company, Kansas City, Mo.

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## Correction

In the article by C. E. Joos, published in the August issue, the titles of Figs. 6 and 7 should be interchanged. The diagram shown in Fig. 7 is that of the feedwater cycle at the Beacon Street Plant of the Detroit Edison Company, and that shown in Fig. 6 is the cycle employed by the Louisiana Steam Products Company.

# Patents*

By GEORGE RAMSEY
NEW YORK
Patent Lawyer
Member A. S. M. E.

## PART II

### The Patent Office

**This month Mr. Ramsey takes us into the U. S. Patent Office and tells us all about that quite amazing organization which is the depositary of some two million patent documents and which represents protection to capital investment running into billions of dollars. Before telling us of its present structure and functioning, however, he gives us an interesting insight into its history, sketching briefly the story of its development from an office presided over by a single clerk to one of the largest and most important of federal departments. It is well for those who have occasion to use the facilities of the Patent Office to know something of its various divisions, their services and procedures. Mr. Ramsey not only gives a clear picture of these things but his article is worth reading as a highly interesting and instructive exposition of a vital Government activity.**

The application for patent having been executed, the applicant usually has the feeling that his part of the proceeding is completed, and that the application is going to the Patent Office in Washington. The Patent Office, to most applicants, is merely a Government institution to which applications for patents are sent and through which patents are granted. This is the extent of knowledge of the majority of the public on this subject. A brief sketch of the historical background and a short survey of the working of this important bureau will increase both our knowledge of and our interest in patents.

When the seat of Government was brought from Philadelphia to Washington in 1800, a single clerk in the Department of State was in charge of patents. In 1801, Dr. William Thornton, a citizen of English birth and very interesting personality, was appointed by Secretary of State Madison to take over this work and was assigned a clerk as an assistant and also a messenger. Dr. Thornton was educated as a physician and had a great interest in scientific matters and was also an architect. He submitted plans for the Capitol Building which were of great interest to President Washington and he was the architect for the building known as the Octagon Building in Washington in which Madison lived for some years. The patent bureau was not established by law but was instituted by Madison as a part of the Department of State. This bureau occupied a part of a two-story house on Eighth Street, between E and F Streets, N.W., Washington and a single pony was kept by the Government for the use of the messenger to ride through the unpaved streets from the patent bureau to the Department of State to carry patents to be signed and sealed.

In 1810, Congress passed a law authorizing the President to erect or purchase "a building suitable for the accommodation of the General Post Office and the office of the keeper of patents."

Pursuant to this law, a building on E Street, N. W., between Seventh and Eighth Streets was purchased. This building was built in 1793 as a hotel and as a playhouse. This was the first theatre in Washington and was known as the "United States Theatre." When the British invaded Washington and burned the Government buildings in 1814, Dr. Thornton appeared on the portico and said: "This is the emporium of the Arts and Sciences of America; don't burn it." The British officer, greatly to his credit, ordered his soldiers to spare this building. The building was enlarged as the business of the post office and of the patent bureau grew but on December 15, 1836, the entire building was destroyed by fire. At this time, the patent force had been enlarged to seven persons including the messenger. After the fire, the bureau took up quarters in the City Hall.

In 1836, Congress recognized the importance of patents and passed the Act known as the Act of 1836, which is the forerunner of the acts upon which the present system is founded. This act established both the Patent Office and the "Commis-

sioner of Patents." This same year Congress provided for the building of a special structure to be known as the Patent Office. This building was to occupy two squares from Seventh to Ninth Streets between F and G Streets. The first Commissioner of Patents was Henry Ellsworth and in his report to Congress after the disastrous fire, he describes the enormous loss and strongly urged that the new building should be fire-proof. According to Commissioner Ellsworth's report, the fire burned one hundred and sixty-eight large folios of records; nine thousand drawings, "some of which were beautifully executed and very valuable"; about ten thousand original specifications of inventions, and about seven thousand models. William P. Elliott was chosen as the architect for the new building. He was the son of one of Dr. Thornton's assistants and had acted as a draftsman in the patent bureau during part of the time his father was in office. The following quotation from the diary of the architect shows an interesting sidelight on President Jackson who ordered that the first wing of the new Patent Office building should be erected on the "southwest corner of the reservation No. 8, instead of the center of the south side, because he did not wish to disturb the log cabin of an old squatter on the public land. I observed that the plan covered the whole square, and that if his order was carried into effect it would destroy the plan. That rather than this should take place, I would give the old woman a residence as long as she lived. He said that his order must be obeyed. The conversation as to the consequences of his order became rather angry. I left him in that mood, and myself disappointed." Apparently, the matter was adjusted to the satisfaction of all parties and the building operations proceeded according to plan. The south wing was completed in 1840 and the Patent Office moved from the City Hall into the new quarters.

In 1877, there was a disastrous fire in the third floor of this supposed fire-proof building in which many valuable records were destroyed.

In 1849, the Department of Interior was formed and the Patent Office was transferred to this Department. The Department of Interior, with its many branches, including Agriculture, Commerce, Labor, (all of which have become independent Departments) and other bureaus such as the Alaskan Commission, the Land Office, the Pension Office, the Indian Office, occupied a part of the new Patent Office building. The Patent Office gradually grew to such an extent as to force out of the Patent Office building all other bureaus and Departments. Finally, the Patent Office increased to well over one thousand persons and became so crowded in the Patent Office building that it was necessary for a further move. In 1925, President Coolidge transferred the bureau of the Patent Office to the Department of Commerce, so that when the Department of Commerce building located between Fourteenth and Fifteenth Streets, and extending from B Street to E Street, N.W., was being built, provision was made for the Patent Office, and in 1932 the Patent Office in its entirety, moved to new quarters in the Commerce building.

We have briefly sketched the growth and changes in the Patent Office in the past and it is expected that the growth will continue into the future. Now we will analyze the Patent Office as it is constituted today.

### *Commissioner of Patents*

The chief executive of the Patent Office is the Commissioner of Patents who is appointed by the President by and with the consent of the Senate, and the Commissioner usually changes when the political complexion of the Administration is changed. The Commissioner, under the Secretary of Commerce, has full charge of the Patent Office, and while his office theoretically includes duties in the nature of administrative, executive, and judicial functions, his time is largely employed in consultation with heads of his departments, attending committee meetings of Congress on proposed changes in the patent laws, and in the general administration of the Patent Office. Because of his position, he may at any time personally take up for consideration any important matter before the office such as unusual and important petitions, or unusual and important problems. In most cases, however, these matters are settled through his assistants. He makes the "Rules of Practice" for the conduct of business of the Patent Office. These Rules of Practice must be under and in strict accordance with the Patent Laws, and must have the approval of the Secretary of Commerce before being adopted. When the Rules are adopted, they have the force and effect of statutes and are binding on the Officials of the Patent Office as well as the body politic at large. While the Commissioner of Patents is politically appointed, he is usually selected from the Patent Bar or from the Examining Corps of the Patent Office. This has been more particularly true in later years than in former years. All business of the Patent Office is conducted in the name of the Commissioner of Patents and all communications must be addressed to the "Commissioner of Patents."

### *Assistant Commissioners*

There are at present three Assistant Commissioners of Patents also appointed by the President by and with the consent of the Senate. These Assistant Commissioners perform such duties pertaining to the office of the Commissioner as he may from time to time assign to them. These duties include consideration of all petitions such as petitions for reviving abandoned cases, petitions to inspect the files, petitions for review of informalities in applications or drawings not provided for consideration on appeal under the Rules of Practice; also, coordinating of the departments of the Office; or other duties which would ordinarily fall upon the shoulders of the Commissioner. In the past, an appeal was allowed to the Commissioner in many cases. This appeal has been eliminated by statute so that the final appellate tribunal of the Patent

Office is the Board of Appeals and in order that the decisions of this Board may have the same force and effect as if the appeal were considered by the Commissioner, one of the Assistant Commissioners sits at each hearing of the Board.

### *Board of Appeals*

The Board of Appeals comprises at present nine members recommended by the Commissioner and appointed by the President by and with the consent of the Senate. These members are usually, although not always, chosen from the Examining Corps. Occasionally, a member of the Patent Bar may be selected by the Commissioner for the position of Member of the Board. It is the duty of the Board of Appeals to hear and decide all appeals allowed by the Rules of Practice. These appeals may include final rejections (that is, a final refusal of the Examiner to allow a claim); final decisions from the Examiner of Interferences such as holding counts (that is, claims involved in an interference) unpatentable; or appeals of a defeated party in an interference. Two members of the Board and an Assistant Commissioner sit at each hearing. Other members of the Board and Assistant Commissioners are free during this time to consider cases which have been heard and formulate their decisions relating thereto.

All other officers, clerks and employees of the Patent Office are appointed by the Secretary of Commerce upon recommendation by the Commissioner.

### *Legal Department*

The legal department, which is closely associated with the Commissioner, comprises a Solicitor and assistants including Law Clerks, all of whom are members of the Bar, and who usually have been members of the Examining Corps. They attend to the legal business of the Office. The laws provide that where an applicant has been refused a patent by the Patent Office, (that is, by a decision of the Board of Appeals), the applicant may appeal to the Courts and in such cases a Solicitor or assistant appears before the Court on behalf of the Patent Office and argues in support of the Patent Office decision. Occasionally, in an interference case, the Solicitor may appear but as a rule only the contestants appear before the Court. Where a mandamus proceeding is brought to compel the Commissioner to act on some matter on which he has refused to act, a Solicitor usually defends the Commissioner in such case. In other words, the Solicitor and his assistants take care of legal matters wherein the Commissioner in his official capacity is involved.

### *Interference Division*

The Interference Division comprises three Interference Examiners and assistants, whose duty it is to handle all interference cases. These Examiners and Assistants are all chosen from members of the Examining Corps. When two or more applicants each attempt to obtain a patent based upon the same invention (though usually in a different form or embodiment), the Patent Office being compelled by law to issue the patent to the first and original inventor, declares what is termed an "interference" which is in the nature of a judicial proceeding to determine which of the contestants is, under the law, the first and original inventor. This procedure is very complex and involves motions, testimony, final hearings, etc.

### *Examining Corps*

The department of the Patent Office with which the ordinary applicant is usually most concerned is the group known as the Examining Corps which examines all applications for patent, the cases being taken up in each Division by the Examiners in chronological order of filing. This does not mean each case in relation to all other cases in the Office are acted on in chronological order, because some Examiners may be further up with their cases than other Examiners even in the same Division. This Examining group is divided into Divisions, of which at present there are sixty-five, and also a special Division for examining applications for design patents. Each of these Divisions has assigned to it certain groups of subject-matter in which applications for patents are to be examined. Each Division is presided over by a Principal Examiner, under whom are First, Second, Third, and Fourth Assistants; the Fourth Assistants being the latest recruits to the Examining Corps. The Examining Divisions have files in which are copies of all United States and most foreign patents pertaining to the particular arts being examined by the Division. These copies of patents are mounted on cardboard and are arranged in cabinets comprising sliding drawers or shoes holding about fifty of the mounted copies of patents. These drawers are arranged in file cabinets according to specific classifications of groups of mechanisms or devices, so that the Examiner studying an application may easily refer to prior art references applicable to the claims of the case being considered. For example, the art of typewriters is sub-divided into many subclasses, one of which may relate to keyboards, another to carriage mechanism, another to frames, etc. The Examining Corps cover the entire scope of the industrial arts, and related arts as nearly as possible are assigned one Division. However, it is not always possible to have the same Division devoted to allied industries. For example, one Division at present is examining the arts of Abrading and Typewriting, which, of course, are unrelated. The assistants, however, who are examining typewriting inventions will not ordinarily be assigned to examine abrading inventions and vice versa. Each Examining Division is a complete entity, having its own clerk and stenographer, and corresponds directly with applicants for patents, all correspondence, of course, being in the name of the Commissioner of Patents.

The members of the Examining Corps are chosen by competitive civil service examination, as are all other employees of the Patent Office, except those

which the law specifically provides may be appointed by the President. The civil service examination for the position of Assistant Examiner in the Patent Office is a very difficult and strict examination which is changed from time to time. A typical examination includes the following subjects: mathematics, through and including calculus; physics, as taught in the higher universities; chemistry, organic and inorganic, quantitative and qualitative analysis; technics which covers the whole of the industrial arts, mechanical, chemical and electrical, including the operation of machines, plants, and everything pertaining to the industrial arts; translations of scientific matter from English into French and German, and translations of a short scientific dissertation from German and French into English; and specification writing, that is, the requirement of writing a description of a machine from a drawing thereof. This description must describe all of the mechanical parts shown in the drawing, part by part, in their relation and operation to other associated parts. If the contestant passes this examination with an average grade of 70 per cent, he is placed on the eligible list as a Fourth Assistant Examiner. In this connection, it is interesting to note that Commissioner of Patents Fisher, in 1869, established an examination as a requirement for prospective members of the Examining Corps. This was long before the adoption of the Civil Service act and is probably the first competitive examination for selection of a Government employee. Before that time, the Examiners were merely political appointees. Commissioner Fisher recognized the necessity of having scientifically trained men as Examiners and this led to the examination system specified. Individual examiners usually work for a long period of time on the same class of inventions. This is of benefit to the applicants for patents and also to the work in the Patent Office because after having been long associated with a particular art, the Examiner's knowledge of the art is such that his labors of searching for references is greatly diminished, and the applicant has the advantage of knowing that his case has been well considered. Not only that, but when an Examiner has been long associated with an art, he becomes more capable of recognizing that apparently a small change may result in a very valuable advance in the art, and, therefore, the longer the Examiner is associated with an art, the more considerate he is liable to become in connection with new applications.

### *Classification Division*

An important division of the Patent Office is the Classification Division presided over by a Principal Examiner, who is in charge of assistant Examiners doing the work of classification. This work involves one of the most difficult problems of the Patent Office, because on the judgment of the Classification Division there depends an orderly arrangement of all patents relating to all the Industrial Arts and Sciences. This work raises very complicated questions where arts overlap such as for example, adding machines and typewriters, the various electrical appliances, etc., and a great responsibility falls upon this division because of the practical necessity of grouping together all related patents in proper classes. It would be obviously impossible for either the Examining Corps or the public to search each of the substantially two million patents to determine the question of novelty of an invention, and validity or infringement of a patent. Therefore, the Classification Division attempts to provide main and sub-classes of inventions relating to a specific subject-matter. If the subject-matter falls squarely on the border line, it is classified in one class and copies called "cross-references" are put in the other related classes. The main classes are divided into numerous sub-classes under the main heading, so that if a question as to a particular part of a device or process is to be investigated, the investigator will find his material so arranged that it does not become necessary to consider every patent in the main class. Where a question arises as to which Division shall examine a border line application, the Classification Examiner assigns it.

### *Chief Clerk*

The Clerical force of the Patent Office carries on the general clerical business of the office and is in charge of a Chief Clerk, who must be qualified to act as a Principal Examiner. The Chief Clerk has several clerical departments under his supervision but his own immediate office is concerned primarily with answering inquiries and with correspondence not specifically relating to the technical matters considered by the Examining Corps. The Patent Office will answer general questions; such as for example, the number of patents in a particular class, or the cost of obtaining certified copies of public records, etc. The Patent Office will not, however, attempt to answer inquiries as to the novelty of a particular invention, nor will the Patent Office give any information, except to duly authorized parties, as to any pending application for patent, because under the Rules, applications for patents are kept in secrecy until the patent is granted, at which time, the application file becomes a public document.

### *Mails and Files Division*

The Mails and Files Division receives incoming mail and distributes the same to the proper section of the Patent Office. It takes care of outgoing and incoming mail. All business before the Patent Office must be transacted in writing, and no attention is paid to any alleged oral promise or stipulation or understanding if a disagreement or doubt arises. All communications leaving the Patent Office are forwarded under Government frank but all communications, telegrams, etc., sent to the Patent Office must be fully prepaid, otherwise they will not be received. Each document forwarded to the Patent Office should be accompanied by a separate letter.

The business of the Patent Office begins at 9:00 A.M., closes at 4:30 P.M. on weekdays, and 1:00 P.M. on half holidays. Special delivery letters and other papers may be deposited in a box provided at the watchman's desk after the Office closes, and papers so deposited are considered as received by the Patent Office on the day of deposit. This sometimes becomes very important because of statutory limitations, one of which is that an Office action in a case must be responded to within six months from the date it is mailed out by the Patent Office, otherwise the application to which it relates will become abandoned. Applications for patents are delivered to the application division, and if complete with filing fee, specification, drawings, etc., will be given a Serial Number and filing date. After the drawings have been inspected by the Chief Draftsman, the applications are distributed to the Examining Corps for examination.

*Draftsman's Division*

The Drafting Division comprises a Chief Draftsman and assistants. All of the drawings of applications are considered by the Chief Draftsman and if they are informal in any way, the Chief Draftsman notes such informality upon the drawing before it is sent to the Examiner's Division. The Draftsman's Division will correct informalities in drawings where possible to do so. No change or correction is made except at the request of the applicant, and no change or addition to the drawings can be made until it is fully approved by the Examiner. Occasionally, it may be necessary to remake or reink drawings and the Draftsman's Division ordinarily will perform this service. There is a charge made for any service performed by the Drafting Division.

*Financial Clerk*

All monies received by the Patent Office go to the Financial Clerk. He accounts for and transfers the same to the United States Treasury. The Financial Clerk may pay out, however, only such monies as are specifically appropriated by Congress and in accordance with the specific authorizations. In the past, it has frequently happened that the Patent Office has taken in in fees considerably more money than Congress has appropriated for the use of the Patent Office. Persons authorized to practice before the Patent Office may maintain a deposit with the Financial Clerk against which certain fees may be charged, such as copies of patents, fees for recording assignments, and other incidental fees involving the business of attorneys practicing before the office. All fees must be paid in advance and must be paid in Specie, Treasury notes, National Bank notes, Post-Office money order or certified checks made payable to the Commissioner of Patents. Money paid in by actual mistake, but not required by law will be refunded, but no refund will be made where a party changes the purpose of payment, such as withdrawing a patent application, or an appeal.

*Assignment Division*

The Assignment Division receives and records all assignments or other documents relating to the title of United States applications or patents. A general contract not involving the title of some specific application or patent ordinarily will not be recorded. There are, however, exceptions to this general practice. A document referring only to foreign applications or patents will not ordinarily be recorded. At present, the recording of these instruments is done photographically so that a true copy of the signatures of the parties is recorded. All assignments are recorded in large volumes known as "Libers" and are open for public inspection. The Assignment Division maintains a Digest of all recorded assignments. The Digest is bound volumes which are very carefully made up so that there is substantial assurance that every recorded assignment is referred to in the Digest. The Digest is arranged alphabetically as to the inventor's name. There is no alphabetical Digest as to the assignee's name. It is a very easy task to run down assignments if the inventor's name is known. It is extremely difficult, however, to run down all patents or applications for inventions assigned to a certain assignee where only the name of the assignee is known.

*Docket Division*

The Docket Division is under a Docket Clerk and assistants, and maintains a docket file of all matters requiring judicial consideration by some branch of the Patent Office, such as petitions, appeals, interferences, etc. This Division keeps the files pertaining to such matters, also all pieces of evidence used in interference cases such as models, paper exhibits, etc., until the contest is closed. Copies of the testimony and formal papers are retained by the Patent Office, but exhibits and models submitted in evidence may be returned to the parties after the contest is closed.

*Manuscript and Lithograph Division*

Manuscript and Lithographic Division attends to furnishing copies of manuscripts or other copies of documents which may be desired by those doing business with the Patent Office, such as photographic prints of drawings of the pending cases, when ordered by authorized persons; photostats of foreign patents; or pages of publications from the library; or in general, such matters as pertain to furnishing the public with copies of such documents as are available to the public. Certified copies of assignments, applications for patents, drawings or any other document available through the Patent Office are obtained from this Division. Certified copies are by statute admitted in evidence in Courts with the same force and effect as the original documents. Consequently, if an original patent is lost or destroyed, a certified copy of the grant and of the specification and drawings of this patent can be used in Court with the same force and effect as the original patent. Of course, fees are charged for this service.

### *Issue and Gazette Division*

The Issue and Gazette Division attends to the preparing of patents for issue, filling out and sealing of patent grants, etc. Each patent goes out under the name of the Commissioner of Patents and is signed by a Law Clerk designated by the Commissioner for this service. This Division also arranges the make-up for the Official Gazette, which is the Official weekly publication of the Patent Office and contains one view of the drawings and a representative claim from each patent issued. It also contains selected decisions of the Courts in patent cases, and by the Board of Appeals, together with other matters of special interest to inventors, including the publication of changes made from time to time in the Rules or Statutes. All patents issue on Tuesday regardless of whether this date shall be a legal holiday or otherwise. All printing of patent specifications, the Official Gazette, and other printing for the Patent Office is done by the Government Printing Office. Subscriptions to the Official Gazette are made through the Superintendent of Documents.

### *Publications Division*

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Dr. Thornton truly epitomized the Patent Office when he said: "This is the emporium of Arts and Sciences of America."

# Combination Waste Heat and Pulverized Fuel Boiler Unit

By W. H. D. CLARK, Combustion Engineering Corporation, Ltd. Montreal

**Mr. Clark tells a very complete story of a highly interesting installation at a large smelter in British Columbia. Many obstacles were hurdled in the design problems of adapting the unit for the use of difficult waste gases in combination with pulverized coal. These problems and the manner in which the design was developed to meet them are related in such detail as to give the reader a clear picture of the job from beginning to end. It is worthy of note that experience and principles, developed in the application of pulverized fuel in power station work, were found to be applicable to many problems in the metallurgical field . . . . This article, presenting as comprehensively as it does the development of design and data of performance and operating experience, will be of particular interest and value to those confronted with similar problems.**

THE history of different basic ideas and conceptions in the engineering world is an always interesting study to those of our calling who have a philosophical turn of mind. These ideas drift constantly into sight, grow, lie dormant, or die, in response to many influences, technical, commercial, or, as often, psychological. The underfeed stoker, for instance, was invented and patented in England one hundred and sixteen years ago, but it came before its time, and the idea died. It had to wait for a saw mill engineer in Oregon, who wanted a machine to burn cord wood to re-invent it. This rapidly developed into a coal burning type which soon became standardized, and then developed slowly until just before the War it received the first of a series of stimulating kicks which have pushed it into its present state—a machine of finished design which can be built in sizes large enough to burn many tons of coal per hr. at efficiencies that a few years ago were thought unattainable.

Pulverized fuel firing is another idea that has had its ups and downs. It flared up at intervals during the last century, but never became commercial, for lack of mechanical and technical assistance of the high excellence required; not until the pre-War part of this century did it settle itself firmly in the firing of cement kilns and different kinds of metallurgical furnaces. For a considerable period it rested there, and then just before the War an inspired mining engineer, named Bettington, burst out, and at one stroke designed a modern steam generating unit. Two of these, built in 1912, are still in operation at Glace Bay, Nova Scotia, and, incredible as it may seem, the design comprises a boiler built around the combustion chamber to form a completely water-cooled furnace, semi-radiant-heat superheaters, shaded by three or four rows of tubes, an air preheater, an air-tight, steel-cased setting, pulverized fuel being supplied by hammer-type pulverizers with cyclone classifiers! But Bettington died fighting the Germans in Africa, and development work died with him. So it was left for the famous group of men who built the Lakeside units, starting where metallurgical and cement mill practice left off, to develop after the War, and patiently refine and perfect the modern steam generator.

This article proposes to describe another swing of the pendulum, and show how the highly developed type of construction, worked out to meet the exacting requirements of the central stations, has returned to its old home in the metallurgical field, where, it is believed, it has a future of unusual promise. The smelting and refining of nonferrous metals is now conducted in such large scale plants that troubles, which used to be merely annoyances, have become serious difficulties. Many of these are similar to problems met in the early days of pulverized fuel's boiler room development, and which the boiler operator (whose sole business is burning coal to make steam) insisted on having eliminated. The enormous expense necessary for this development could never have been justified if spent solely on auxiliary equipment of the smelting industry, but solutions have been worked out for many problems common to both fields.

The Consolidated Mining and Smelting Co., of Canada, Ltd., at their Trail Smelter, in British Columbia, has developed a process for recovering the zinc present in appreciable quantities in the

slag from the lead blast furnaces. This is done by pouring the molten slag into a rectangular, water-cooled furnace and injecting pulverized coal and compressed air beneath the surface of the slag pool. Some combustion beneath the surface of the bath causes a series of small explosions, resulting in violent turbulence. The CO formed by the incomplete combustion at this stage reduces the zinc combined with the slag as oxide, and it fumes off as metallic zinc vapor. This, on leaving the bath, burns to oxide again along with the remainder of the combustible from the coal. In order to keep the reducing action as great as possible, the furnace proper is operated with no excess air. This slag retreatment furnace is one of two comprising the final scheme, and it, and the future one, are arranged to discharge into one side of a large brick inter-connecting flue, approximately 12 ft. high by 11 ft. wide. From the other side of this flue the gases enter the waste heat boilers, thence through a long hopper bottom flue to an economizer from which they are delivered to a bag house. Much of the zinc dust settles out of the gas stream into the various hoppers along its path, and final dust recovery is effected in the bag house. This dust is then sent to a special leaching plant where it undergoes a carefully developed purification treatment before joining the zinc extracted directly from the ore by the ordinary electrolytic process. Two boilers are installed, and space is arranged for a third one in the future. They are large boilers, each having 17,000 sq. ft. of heating surface, and as a startling indication of the importance of this process as a producer of zinc, it is noteworthy that the original scheme included a condenser, capable of absorbing the entire steam output and wasting the heat to the river. That is, this large and expensive boiler installation, comparable with the boiler room of a 20,000 kw. station could be operated, if necessary, solely for cooling the gases so they could enter the bag house with safety. This was, of course, not its only purpose, for the steam output was intended to replace the numerous small boilers in different boiler houses through the plant.

After the installation was put in operation in 1930 the steam demand steadily increased until in the spring of 1931 it was apparent that extra capacity would be required to carry the plant through the winter successfully. This was due to the increased demand which had developed as the result of the addition of the Fertilizer Department to the Tadanac Works. Sulphurous gases (which had previously been wasted) from the roasting of zinc concentrates, were turned into the sulphuric acid used in the manufacture of various fertilizers. It was, therefore, decided to remodel one of the waste heat units, normally held as a spare, to also burn coal in a water cooled furnace. The plant operators, moreover, wished to take advantage of the change-over to incorporate features which experience had shown would be advantageous when operating as a waste heat unit.

The problem of designing the new furnace was a fairly difficult one. As a coal-burning unit it was required to develop as large a capacity as possible; 3000 boiler hp. was set as a desirable figure, and when it was found that sufficient furnace volume could be provided this was raised to 4000 hp. It was also desirable to operate at very low ratings on occasion, for it was possible that during the summer the waste heat from the slag retreatment furnace would almost meet the steam demand. The fuel to be burned was coal from the Crowsnest Pass district of Alberta, having a typical analysis:—

| | |
|---|---|
| Volatile | 21.7 per cent |
| Fixed carbon | 58.7 per cent |
| Ash | 19.6 per cent |
| B.t.u. | 11,950 per lb. as fired |

This coal was ground in an existing central preparation plant, so that 80 to 85 per cent would pass through a 200 mesh screen. Similar fuels had been burned at two different pulverized fuel plants in the Canadian West; one a vertically-fired, storage-system installation, with refractory furnaces, and the other a horizontally-fired, unit-system installation with bare-tube, water-cooled furnaces. Since the only furnace arrangement possible at Trail required the use of horizontal burners, the latter plant was selected for comparison. Experience there had shown that while the burning characteristics were not as desirable as those of a high-volatile coal, nevertheless good results could be secured. Test figures at this plant (a 600 hp. boiler equipped with an air preheater) showed the following performance, at a load of 44,750 lb. of steam per hr., from and at 212 deg. fahr.

| | |
|---|---|
| Loss due to dry stack gases | 6.86 per cent |
| " " " moisture in fuel | .56 per cent |
| " " " " from hydrogen | 2.86 per cent |
| " " " carbon in refuse | 2.50 per cent |
| " " " radiation | 2.00 per cent |
| " unaccounted for | 1.12 per cent |
| Heat absorbed by boiler, superheater and preheater | 84.10 per cent |

This fuel, however, had been found to give a long flame, so that an important point in the furnace was the provision of ample flame travel. In the final furnace design the shortest possible distance from burner outlet center line to boiler tubes was 22 ft., and the probable flame path was 28 ft. This considered together with a combustion rate of 22,000 B.t.u. at full load, indicated that the furnace designed was adequate for 4000 hp. The beneficial effects of preheated air available at the other plant were lacking, but Trail had the advantage of being fired by the storage system and the accurate control of primary air secured by this would be an important compensating factor. The use of an air preheater at Trail was considered, but the excessive and unpredictable air leakage through the flue meant that a very uncertain proportion of the total air would pass through it at the lower ratings; since heat recovery was therefore uncertain the air preheater was not installed.

Provision was made for its addition in the future, if justified by installing fans of the required capacity.

The waste heat side had many difficult points in it, for although it was expected that only occasionally would the waste gases be passed through this boiler, still it was necessary, in order to provide reliability, to design the setting as if this gas were to be the steady diet. Most of the decisions on the furnace design, therefore, were made primarily from this viewpoint and then checked to make sure they would not interfere with pulverized fuel operation.

The gas carried about five to six tons per hr. of solid material, running 50 to 60 per cent zinc, 10 per cent lead, and small amounts of silica, iron, sulphur, etc. This was a concentration of solids much higher than anything encountered in ordinary boiler practice, for it amounted to 7 per cent of the furnace gas by weight (in a standard pulverized fuel furnace, burning coal of 20 per cent ash content, this figure is about 1.8 per cent). The low excess air resulted in such a long flame and high temperature that the gases had been found entering the boiler as high as 2700 deg. fahr. This combination of high temperature and heavy dust burden furnished the essential materials for a slag problem which would be major or minor, depending on the exact characteristics of the dust itself. The zinc fume comprising the major portion of this dust was not easily fusible, but the remainder had unfavorable characteristics. There were particles of lead slag blown over from the bath and from the addition of coal slag. There was also the slag formed by the reaction between the metallic oxides present in the dust and the silicates of alumina in the coal ash, and this was the most important source of slag trouble. Wherever this siliceous ash would settle there would also settle some of the fume and in the boiler there was a preferential precipitation of lead. Lead oxide is an efficient flux, thus the melting point of the ash was lowered, causing slag to form and build up wherever the temperature was high enough. The ash particles would likely soften somewhat as they remained in place, but much of the slag was formed in place. This fluxing action of metallic oxides, particularly lead, which lowers the melting point of all silicates, is similar to the effect of certain coal ashes. A certain eastern Canadian coal, for instance, yields an ash containing about 35 per cent of iron oxide, and when this coal is burned in pulverized form, where the ash is sprayed freely about the furnace, the slagging troubles encountered with brick walls are so serious that this type of wall has been almost wholly superseded by water cooled construction.

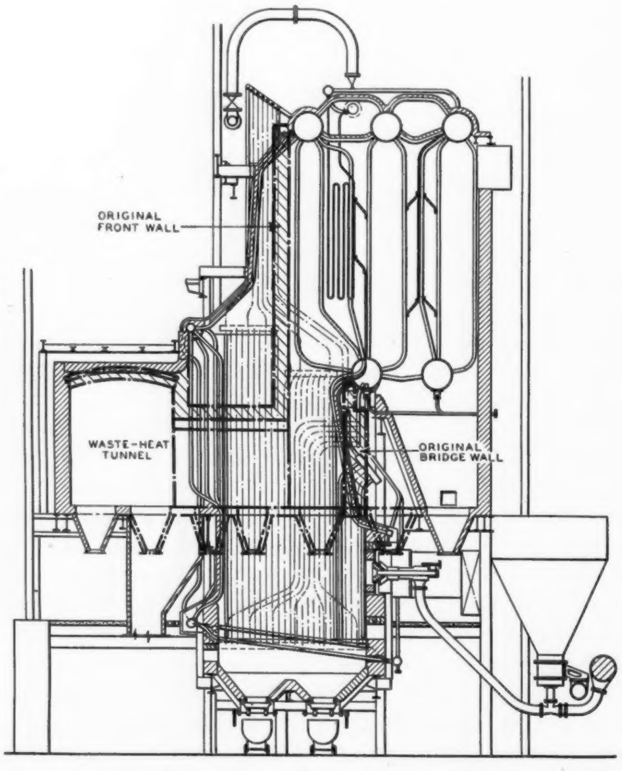


**Fig. 1—Sectional elevation of unit with outlines of original arrangement shown by heavy dot and dash lines.**

In addition to the building up of deposits on the walls by this mechanism there were parts of the flue system where conditions were favorable to the formation of a fluid slag with consequent erosion of the refractory. This phase of the problem was not as serious as the building up of deposits, however, for apparently the rate of reaction between the metallic oxides and the siliceous ash and refractory was rather sensitive to temperature. This resulted in the brick walls, in the locations subject to erosion, melting at an extremely slow rate after a thickness of 9 to 13 in. was reached. This is quite different from the characteristics of the coal slag mentioned above, for walls attacked by it seem to have no terminal thickness. Cases are known where the slag-refractory reaction has proceeded at an undiminished rate to a wall thickness of three inches, indicating a rate of reaction unaffected by a wide range of temperature.

The original arrangement of the boiler and flue is shown by the heavy dot and dash lines in Fig. 1. It will be noted that the arrangement is a good example of waste-heat design for service where the dust is present as a dry powder, this being the condition that was anticipated when the plant was designed. Since, however, the dust was actually present in the troublesome sticky state of slag, the problem had to be approached from an entirely different angle.

One of the first necessities, therefore, was a great increase in the area of the gas entrance to the first pass, for it is obvious that, other things being equal, the tendency of a tube bank to slag up solidly is some function of the pounds of slag per minute thrown against each sq. ft. of gas opening.

The wall in front of the boiler was, therefore, moved away as shown in Fig. 1, to allow the gases to enter freely over practically the entire face of the front bank. This was not undesirable for coal firing either, but the fear of almost entirely short circuiting the superheater led to this being revised in the final design shown in Fig. 2. This was particularly necessary, since when burning coal the

high proportion of water cooled furnace wall would probably reduce the superheat materially even if the gas were flowing through the superheater. This has fulfilled its purpose excellently, the stream of hot gases being largely deflected into the boiler tubes by the inclined middle portion of the front wall.

The second step taken was the enlargement of the opening from the flue to the boiler furnace. This was originally constructed as two brick tunnels, with a water-cooled damper in each to shut the boiler off from the flue when required. With the proposed furnace there was no hope of retaining these dampers in this position, so they were moved into the flue itself, close to this boiler. Then when the heavy steel supporting the dust hoppers was cut away, this left free scope in elaborating the design of the new waste gas entrance. It was decided to run a slag screen across this opening, using vertical tubes. This would cool the waste gases entering the furnace somewhat. It would have the same effect as the slag screen arrangements frequently built into the front bank of large boilers, only the point where the slag first impinged on cold tubes would be transferred to a location where the freest possible access for cleaning could be provided. It will be seen in Fig. 2 that three rows of tubes were used, the rows being 18 in. apart, and the tubes in each row on 14 in. centers. This provided wide angular lanes for the gas flowing along the flue to turn into the boiler, and kept the tubes sufficiently far apart to minimize the danger of slag incrustations bridging from one tube to another. To further cope with such a situation the final design provided a continuous row of doors at the top of the screen to facilitate slicing slag off; and ample doors were provided in the back of the hopper under the main brick flue.

It was calculated that the normal gas flow would not fill more than the upper half or two-thirds of the opening provided, and as any serious slagging of the screen would almost certainly start at the top and progress downwards, this meant that as the screen slagged up the gas flow would move down to an area where poking and cleaning could be more readily performed.

In the final design the gas flow entering the furnace was radically altered. It had been originally intended to lead this to the boiler tubes in as direct a path as possible, but as the design was being worked out it became apparent that this path washed a very small area of the water cooled side walls, so that the benefit of possible cooling by these walls was largely lost. The upper header of the slag screen was, therefore, dropped to the lowest possible point, and the slag screen tubes were finned for some distance below this to act as a baffle, and make the gas enter as low as possible. Then to increase the water cooled wall area, the riser tubes from the upper side wall headers were bent back inside the furnace and run vertically up the furnace face of the brick walls. This required a rather special design for the protection and seal-

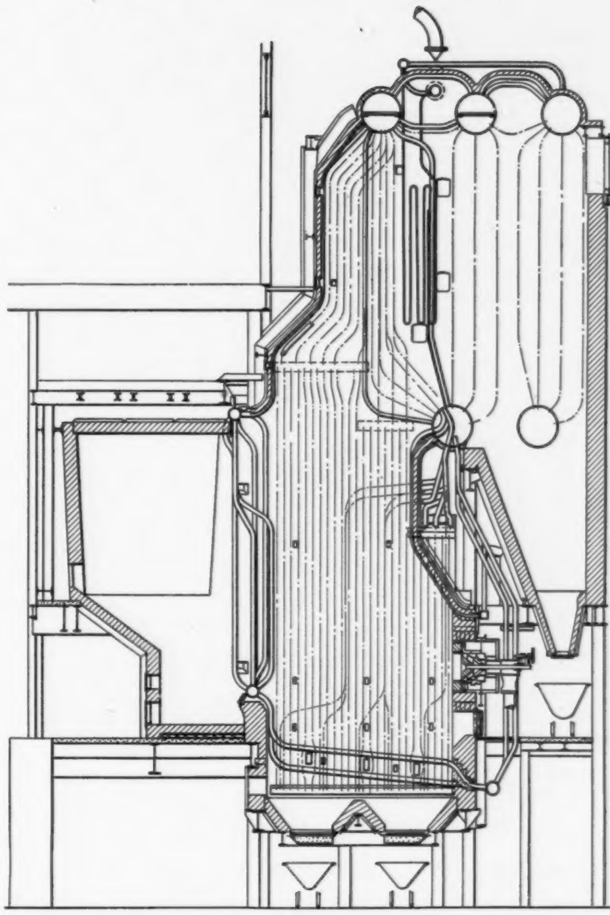

Fig. 2—Sectional elevation showing final design of unit.

ing of the headers, but it had other advantages in eliminating all outside circulation tubes from the upper part of the boiler room. These changes to the design brought the flow of the waste gases more in line with ordinary boiler furnace conditions. Due to the scanty information available covering gases with such high dust content, exact calculations of the radiant heat absorption in the walls could not be made, but in a general way it was known that in a boiler furnace with horizontal firing and bare tube walls the boiler tubes do not slag up unless the flame washes them heavily for a long period. The lower part of such a furnace is unquestionably full of gas carrying molten slag, and the furnace bottom may even be a pool of slag. This freedom from slagging troubles has been secured even with coals whose ash softens at 1800 or 1900 deg. The boiler, therefore, would probably be safe against slagging unless the low excess air in the slag retreatment boiler resulted in the flame being so long that it entered the boiler tubes still burning. This was unlikely in this instance on account of the great length of the connecting flue providing ample travel to complete combustion, but it is a point which should not be forgotten when considering such cases generally; cases are known where the flame is still burning briskly in the second pass of the boiler, and in these something more drastic than a slag screen and water-cooled walls are required to eliminate slagging.

To all these precautions against slagging

troubles was added another one, which is probably unique. There existed a certain danger of large slag masses accumulating on the walls and then falling on the ash pit screen and wrecking it. This was considered hardly possible, for boiler furnace walls of the bare tube type have not been known to accumulate such masses, but the result of such an accident would have been disastrous. To abandon the ash pit screen and use a hopper bottom was one solution, but not a satisfactory one; years of experience having shown that a properly designed screen would cool the ash pit zone most effectively under almost any conceivable furnace conditions. To stiffen the screen, therefore, was the best solution, and provision was made in the side walls for the insertion of water cooled beams under the upper row of tubes. This would constitute a solid grillage which would be safe against falling slag. The idea of water cooled beams in a furnace will probably curl the hair of a power plant man, but even more heretical things were done here. It will be noted that the bottom header of the slag screen is wholly in the furnace, and has its handhole cap protected by three water cooled pipes. This arrangement could not be avoided; structural interferences and screen design requirements eliminated other locations. The main object of this header was to provide a junction between the slag screen and the brick partition wall to which slag would not adhere and start the screen filling with slag. No experience is available with the water cooled beams, since they have not been required so far, but the header cap water cooling has been in continuous service for four months with no signs of trouble developing. It gives every indication of being entirely reliable. In case the adverse conditions contemplated did develop, and large pieces of slag had to be handled, provision was made to get these into the ash pit by omitting a few rows of ash pit screen tubes at each side. This left a wide gap, and the large pieces could be worked over and dropped through these. To facilitate this, observation and access doors were placed around the furnace at the screen level,

Fig. 3—View of interior of furnace taken during construction.

in almost every possible location, including four large doors under the burners. These latter, due to interferences with downtake tubes, burner wind boxes, air ducts, and fuel pipes, turned out to be one of the most serious difficulties in the detail engineering work, and many studies had to be made before a satisfactory layout was obtained.

As mentioned above, it was desirable to secure as large an output as possible from the unit, and 4000 hp. was set as the required figure. With the furnace volume provided, this corresponded to a combustion rate of 22,000 B.t.u. per cu. ft. per hr., which was not an excessive figure, in view of the shape of the furnace. The flame from burners of this type is not a uniform bushy shape, but is lifted upward by the rising column of hot gas into a shape not far removed from the cross section of this furnace. This meant that the combustion rate was conservative, since it was not based on any dead furnace volume which could not be filled by flame. While the fuel burning side was thus satisfactorily taken care of, the steam generating side was not. It was obvious at a glance that 4000 hp. was excessive for a waste heat unit which had been carefully and accurately proportioned to generate 1700 hp. On checking the boiler for operating characteristics at this high capacity it was necessary to make several changes; the front drum was fitted with perforated baffle plates at the water line to reduce the violent disturbance of the water in it, extra water circulating tubes were designed to connect the front and middle drums, and extra steam circulating tubes were installed to connect the middle and rear drums. These changes were relatively simple in themselves, but the designing of them was work of the most difficult nature, involving, as it did, a complete analysis of an unusual type of boiler operating under conditions for which it was never intended. Experience, however, was available from the large number of vertical and inclined tube boilers which have been installed in the last few years for operation at high ratings. This enabled operating conditions to be predicted with considerable accuracy. It was finally decided that operation at 4000 hp. was practical, but that this was close to the safe limit. In service, no trouble has been encountered up to this point, but on one occasion when the output was pushed up to 4400 hp. it was found that any disturbing influence, such as sudden load or feedwater change, resulted in erratic behavior. After operating experience during a five months' run it has been decided that 4175 hp. is the limit at which the boiler is capable of operating satisfactorily. It is believed that this result—constituting not simply the provision of a safe operating margin, but the accurate prediction of operating conditions— is a noteworthy indication of the careful technical work done on boilers in the last few years.

The engineering work of designing equipment to meet the various special requirements was difficult, and this was amplified by the long distance between the designing office in New York and the site of the work in Trail. The cooperation of the Con-

solidated Mining and Smelting Company engineers in furnishing information, checking drawings, and in adapting their share of the design work, was whole-hearted and energetic. It resulted in the designs for the extensive and intricate changes reaching completion with an accuracy which was demonstrated in the rapid progress of the construction work. The boiler was shut down on October 6, 1931. The work of wrecking the then existing firebox and preparing for the building steel changes was commenced on this date, and actual alterations to the boiler and setting were commenced one week later, on Oct. 13. All alterations were completed on Nov. 22, and the boiler subjected to a hydrostatic test on the following day, everything being found satisfactory. Contrary to the usual practice in this class of construction, no specialist workmen were imported, and the entire job, including drilling nearly 300 tube-holes in the drums, was done by a crew made up from the plant's regular construction force. To complete such a job in 48 days is unusually quick work.

A drying fire of wood was started with the intention of drying out the setting slowly for a week, but the condition of the slag retreatment furnace made it necessary to put the boiler on the line on November 24 after a drying period of only 16 hr. The boiler then operated continuously until April 2, 1932, when its output was no longer required, and it was shut down.

Some trouble in maintaining a clear fire and stable ignition was experienced at first, for the fuel is very sensitive, and it was necessary to work out correct adjustments to suit it.

At high ratings the unit has been found easy to operate. On December 13 it delivered steam at an average rate of 120,400 lb. per hr. for 24 hr., from 12 noon to 5 p.m. of this day its output averaged 130,000 lb. per hr. At a load of 100,000 lb. per hr. a five-hour observation gave the following results:—

| | |
|---|---|
| Date | December 17, 1931. |
| Duration of Test | 8 a.m. to 5 p.m. |
| Steam Conditions | 180 lb. per sq. in.— 420 deg. total temp. |
| Feedwater | 180 deg. fahr. |
| Total Steam Generated | 499,800 lb. |
| Total Coal Burned | 56,505 lb. |
| Actual Evaporation | 8.84 lb. |
| Equivalent Evaporation | 9.79 lb. from and at 212 deg. |
| Boiler and Furnace Efficiency | 79.8 per cent |

This figure may be compared with the results previously noted at another plant. The efficiency there obtained was 84.1 per cent, and this at almost exacly the same boiler rating. This comparison plant included an air-heater which at this rating cooled the boiler exit gas about 200 deg. If Trail were similarly equipped, the dry gas loss would be reduced by 4.8 points, increasing the efficiency to 84.6 per cent—an extraordinarily close check. This is a most satisfactory result, indicating that Trail, in spite of the numerous departures from conventional design which were made for the benefit of the waste gas, is being operated as efficiently as a standard central station unit.

**Fig. 4—View from entrance flue, showing slag screen through which waste gases enter furnace.**

There was, however, considerable trouble at the low loads, and for some time it was impossible to get below 25,000 lb. per hr. To remedy this, the fuel pipe to one burner was changed from 10 in. to 8 in. dia., and the lowest speed of the coal feeder was reduced. It was then found possible to operate as low as 15,000 lb. per hr.—a ratio of high to low load of 8.5 to 1.

The efficiency, however, at this low rating, is very poor, being 40.2 per cent. This load corresponds to about 31 per cent of nominal boiler rating, and to a combustion rate of only 4600 B.t.u. per cu. ft. per hr. The heavy combustion losses at this rating probably comprise 5 or 6 points for the extra effect of the radiation loss, 10 to 20 points for extra dry gas loss caused by the disproportionate effect of air infiltration, and the remainder, 13 to 24 points, extra carbon loss due to poor flame conditions. An increase of carbon in the refuse from 20 per cent to say 50 per cent would explain this. The poor flame condition is due to causes common to all large units at extremely low ratings, which all center around poor mixing with a resultant long and lazy flame.

The opinion of the operators is that the boiler itself has a safe steaming limit of about 130,000 lb. per hr. At this load the water in the columns begins to act in the erratic manner usual when a limit is about reached.

The operating experience with gas from the slag retreatment furnace is most interesting, for

although steam generation from coal was the principal object of the installation, nevertheless a great deal of the design work had been done with waste heat in mind. Unusually full information is available on this phase of the work.

There had been little expectation that coal could be burned when the boiler was handling waste gas. The low volatile, high ash, coal was sufficiently sensitive to make it a problem in itself without having the furnace full of non-combustible dust, and practically inert gas. The first attempts made to burn coal during a gas run did not meet with much success, but later after more experience with the burners no difficulty was encountered, and it was found possible to cut off the coal supply and start it up again at will. This is a remarkable achievement, and the plant operators deserve credit for solving what must still be regarded as a very difficult problem.

The final design of the flue slag screen had been governed by:—

(1) structural requirements,
(2) water screen circulation requirements,
(3) baffle requirements, for waste gas flow,
(4) cooling the waste gas entering the furnace.

With these various limitations of the design, accessibility for cleaning was not as good as could have been wished, and with the dense fumes prevailing this has constituted a major difficulty. The screen has to be cleaned entirely by touch, and the operators have been unable to prevent a layer of slag building up on the tubes; when the unit was shut down this was found to be 3 in. thick. Slag also collects on the lower header, and it is believed that on a prolonged run this would be the limiting factor which would necessitate a shut down. It is believed that this experience points the way to a much better line of attack, and it is now felt that adequate water-cooled combustion space before the boiler is the answer to a problem of this type.

The performance of the water walls in the boiler furnace has been considerably better than expected, for when the unit was shut down these walls were found to be clean. As mentioned previously, numerous precautions were taken to guard against trouble resulting from heavy slag formations on the walls, but this condition has not developed. This boiler, moreover, has been found to generate slightly more steam on waste heat than the other boiler in the plant. The other boiler is directly opposite the furnace while this one receives its gas through a long brick connecting flue from which there must be a substantial heat loss.

It is believed that the history of this unique installation at Trail, has in it some very definite indications for future work in the metallurgical field.

(1) The highly developed central station type of pulverized fuel equipment can be installed with confidence in its reliability. This furnace went into operation after a 16 hr. drying period and remained in operation continuously for five months.

(2) Central station efficiency can be achieved, in spite of the handicap imposed by special requirements. This furnace equals, or slightly betters, the performance of a standard unit in a public utility.

(3) The slagging troubles encountered are sufficiently akin to known boiler furnace troubles for the same rules of behavior to hold good with proper modifications. The difficulties are greater, but they are of the same sort—they are not new varieties.

(4) Water cooled wall construction can be successfully applied to cope with slag adhesion or refractory erosion. There are good grounds for believing that given a specific case, a boiler and setting can be designed which can operate continuously as long as the furnace can. It is believed that in a new installation, where free scope is allowed, this can be assured even with the most unfavorable conditions.

The writer was closely concerned with this installation from its inception to the completion of the work, and wishes to take this opportunity of expressing his deep appreciation of the wholehearted cooperation of the Consolidated officials and engineers concerned in the execution of the work.

While the Consolidated Mining and Smelting Company has very courteously furnished full extracts from its operating logs to assist in the preparation of this paper, the presentation of this material herein, and the conclusions drawn therefrom, must be taken as representing the personal viewpoint of the writer.

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**Manning, Maxwell & Moore, Inc.,** New York, announce the acquisition of the business of the Box Crane & Hoist Corporation, Philadelphia. The transaction is to be effected on a cash basis; there will be no exchange of securities. The plan is to merge the business thus acquired with that of the Shaw Electric Crane Company, a Manning, Maxwell & Moore subsidiary, in the Shaw plant at Muskegon, Mich. The merged business will operate as the Shaw-Box Crane & Hoist Co. The purchase does not include Philadelphia land and buildings.

---

**The Swartwout Company,** Cleveland, announces the appointment of Henry C. Miller as Sales Manager of their Power Plant Equipment Division. During Mr. Miller's twelve years' experience with The Swartwout Company, he has served in responsible positions in connection with the design, manufacture, sale and service of Swartwout power plant equipment. Five years ago this division of the company purchased the "S-C" Regulator Manufacturing Company of Fostoria, Ohio. Mr. Miller is now responsible for the sales of the complete line of equipment.

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**The Davis Engineering Corporation,** New York, have added to their staff the Arthur S. Hall Company, Worcester, Mass., to represent the Paracoil line of domestic hot water heaters in that territory.

# Empirical Equations

By

DALE S. DAVIS

Consulting Mathematican

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**After reading Mr. Davis' article "Graphical Representations of Engineering Equations," published in the December, 1931 issue of COMBUSTION, one of our readers wrote us stating that the article had helped him with certain problems with which he had been having difficulties due to the fact that his knowledge of mathematics had become rather rusty. He suggested that an article on the derivation of empirical equations would, in his opinion, be helpful to many engineers. We agreed with him and accordingly invited Mr. Davis to prepare the present article which we hope will be of value to many of our readers whose memories need a little freshening and to others whose mathematical education has been limited. . . . The author takes actual data of problems related to steam plant operation and derives equations, giving in all ten typical forms of equation. Apparent discrepancies in the sequence of numbers of charts and tables are due to the fact that they are numbered to correspond with the equation numbers.**

IN making the most of a set of experimental data it is generally desirable to express the relationship between the variables in the form of an equation. In view of the necessarily approximate nature of the functional relationship such an equation is described as "empirical" although no particular stigma should be attached to the name since many ultimately recognized chemical, physical, and biological laws have started out as empirical equations.

The first step in the determination of the equation is that of plotting the data on ordinary coordinate paper, while the second step is that of attempting to identify the plot with one of the familiar types of curve: the straight line; the parabola, the hyperbola, etc. Frequently the arrangement of the plotted points will suggest the type of equation to be employed. In any case, the third step of the curve-fitting process is that of "rectifying" the data, i.e., of plotting such functions of the variables that a straight line will result.

The fourth step of the process, that of determining the constants in the equation, depends upon the precision of the data, the use to which the equation is to be put and the time which can profitably be expended. In many cases where the data are not extremely precise, when but little time can be spent in curve-fitting or when only a roughly accurate equation is needed, the constants may be determined by inspection of the straight-line plot, directing particular attention to the matter of intercepts and slopes. In instances where the data warrant extreme accuracy and considerable expenditure of time, the method of "least squares" is used in arriving at the constants.

In most cases encountered by the engineer the constants are determined by the method of averages whereby values of the rectifying functions, arranged in ascending or descending order with respect to at least one of the variables, are divided into two sets containing approximately the same number of pairs of values. The two sets are summed separately resulting in two equations which are then solved simultaneously for the values of the constants involved. The exact procedure will be discussed more fully in connection with the examples.

It is the purpose of this paper to follow through, in some detail, the four steps in the determination of empirical equations of the most common types. The illustrations all embody actual data, taken, for the most part, from recent issues of *Combustion* and other engineering publications.

The following table lists the ten most common forms of equation and the functions to plot in order to rectify the curve:

| Type No. | Form of Equation | Functions which Plot as Straight Line if Form of Equation is Suitable |
|---|---|---|
| (1) | $y = a + b x$ | $y$ vs $x$ |
| (2) | $y = a x^b$ | $\log y$ vs $\log x$ * |
| (3) | $y = a x^b + c$ | $\log (y - c)$ vs $\log x$<br>First, plot $y$ vs $x$ on ordinary coordinate paper and choose the points $(x_1, y_1)$ and $(x_2, y_2)$ on a smooth curve drawn through the plotted points, noting the value of $y_3$ where $x_3 = \sqrt{x_1 x_2}$. Then $c = \dfrac{y_1 y_2 - y_3^2}{y_1 + y_2 - 2 y_3}$ |

* Logarithms to the base 10 are used throughout this paper.

| | | |
|---|---|---|
| (4) | $y = (10)^{a+bx}$ | $\log y$ vs $x$ |
| (5) | $y = (10)^{a+bx} + c$ | $\log(y - c)$ vs $x$<br>First, plot y vs x on ordinary coordinate paper and choose the points $(x_1, y_1)$ and $(x_2, y_2)$ on a smooth curve drawn through the plotted points, noting the value of $y_3$ where $x_3 = \frac{x_1 + x_2}{2}$. Then $c = \frac{y_1 y_2 - y_3^2}{y_1 + y_2 - 2 y_3}$ |
| (6) | $y = a + bx + cx^2$ | $\frac{y - y_1}{x - x_1}$ vs $x$<br>First, plot y vs x on ordinary coordinate paper and choose any point $(x_1, y_1)$ on a smooth curve drawn through the plotted points. |
| (7) | $y = \frac{x}{a + bx}$ | $\frac{1}{y}$ vs $\frac{1}{x}$ |
| (8) | $y = \frac{x - x_1}{a + bx} + y_1$ | $\frac{x - x_1}{y - y_1}$ vs $x$<br>First, plot y vs x on ordinary coordinate paper and choose any point $(x_1, y_1)$ on a smooth curve drawn through the plotted points. |
| (9) | $y = a + bx + (10)^{c+dx}$ | Represent part of the data by $y' = a + bx$. Calculate $\delta = y - y'$ for values of x in the curved portion. Represent $\delta$ by $(10)^{c+dx}$. |
| (10) | $y = a + bx + cx^2 + dx^3$ | Choose four points well distributed over the range of data and set up four equations of the form of Type No. 10. Solve simultaneously for a, b, c, and d. |

*Examples:*

### Type No. 1 $\quad y = a + b x$

Data on the relation between the thermal value, H, B.t.u. per pound, and the percentage ash content, A, of Pennsylvania anthracite silt, (Patterson, *Combustion,* 3, No. 10, 17, 1932), are given in Table I. Both the thermal value and the ash content are on the dry basis.

TABLE I

| H (Obsd.) | A | H (Calcd.) | Per cent deviation |
|---|---|---|---|
| 12,200 | 17.5 | 12,180 | —0.2 |
| 10,750 | 26.0 | 10,760 | 0.1 |
| 9,400 | 34.0 | 9,420 | 0.2 |
| 7,600 | 44.5 | 7,670 | 0.9 |
| 6,700 | 49.0 | 6,920 | 3.3 |
| 5,950 | 56.5 | 5,670 | —4.7 |

A plot of the data, Fig. 1, on ordinary coordinate paper suggests a linear relationship between the variables:

$$H = a + b A$$

Substituting the data in this expression we may write the six equations,

$$\begin{aligned} 12{,}200 &= a + 17.5\ b \\ 10{,}750 &= a + 26.0\ b \\ 9{,}400 &= a + 34.0\ b \end{aligned}$$

$$\begin{aligned} 7{,}600 &= a + 44.5\ b \\ 6{,}700 &= a + 49.0\ b \\ 5{,}950 &= a + 56.5\ b \end{aligned}$$

Dividing into two groups of three equations each and adding each group we have,

$$\begin{aligned} 32{,}350 &= 3\ a + \ \ 77.5\ b \\ \text{and}\quad 20{,}250 &= 3\ a + 150.0\ b \end{aligned}$$

which, solved simultaneously, yield a = 15,100 and b = —166.9, making the empirical equation read

$$H = 15{,}100 - 166.9\ A$$

Table I gives a comparison of the observed and calculated values of H and also lists the percentage deviation of each calculated value from the corresponding observed value.

### Type No. 2 $\quad y = a x^b$

Report No. 176 from the Technical Research Department of the International Combustion Engineering Corporation embodies a plot of

$$\frac{\Delta P \rho}{\left(\frac{G}{1000}\right)^2} \times 10^6 \text{ vs } \frac{B G}{1000 \mu} \times 10^{-3},$$ covering laboratory tests on plain tube economizers,

where $\Delta P$ = Pressure drop in inches
$\rho$ = Density of gas, lb. per cu. ft.
$G$ = Mass velocity of gas, lb. per hr.
$B$ = Horizontal clearance between tubes in inches
and $\mu$ = Viscosity of gas.

The data are presented in Table II, where, for convenience, we let $y = \frac{\Delta P \rho}{\left(\frac{G}{1000}\right)^2} \times 10^6$ and $x = \frac{B G}{1000 \mu} \times 10^{-3}$

TABLE II

| y (Obsd.) | x | log y | log x | y (Calcd.) | Per cent deviation |
|---|---|---|---|---|---|
| 84.0 | 9.6 | 1.9243 | 0.9823 | 86.9 | 3.5 |
| 87.0 | 11.3 | 1.9395 | 1.0531 | 83.4 | —4.1 |
| 79.0 | 14.0 | 1.8976 | 1.1461 | 78.8 | —0.3 |
| 74.0 | 17.1 | 1.8692 | 1.2330 | 74.6 | 0.8 |
| 68.0 | 21.8 | 1.8325 | 1.3385 | 70.0 | 2.9 |
| 64.0 | 34.2 | 1.8062 | 1.5340 | 62.5 | —2.3 |
| 58.0 | 46.0 | 1.7634 | 1.6628 | 58.1 | 0.2 |

Fig. 2a indicates that a plot of y vs x on ordinary coordinate paper is not linear while Fig. 2b shows that a plot of y vs x on logarithmic paper (equivalent to plotting log y vs x on ordinary coordinate paper) is linear and suggests that the empirical equation will take the form

$$y = a x^b$$

or, on taking logarithms of both sides of the equation,

$$\log y = b \log x + \log a$$

Substituting the data from Table II into the logarithmic equation, we have the following seven equations:

$$
\begin{aligned}
1.9243 &= 0.9823\ b + \log a \\
1.9395 &= 1.0531\ b + \log a \\
1.8976 &= 1.1461\ b + \log a \\
1.8692 &= 1.2330\ b + \log a \\
\hline
1.8325 &= 1.3385\ b + \log a \\
1.8062 &= 1.5340\ b + \log a \\
1.7634 &= 1.6628\ b + \log a
\end{aligned}
$$

Adding the first four equations and the last three we have,

$$7.6306 = 4.4145\ b + 4 \log a \qquad (1)$$
$$5.4021 = 4.5353\ b + 3 \log a \qquad (2)$$

Dividing equation (1) by 4 and equation (2) by 3,

$$1.9077 = 1.1036\ b + \log a \qquad (3)$$
$$1.8007 = 1.5118\ b + \log a \qquad (4)$$

which yield, on subtraction,

$$
\begin{aligned}
0.1070 &= -0.4082\ b \\
\text{or}\quad b &= -0.2621
\end{aligned}
$$

Substituting for b in equation (3),

$$
\begin{aligned}
\log a &= 1.9077 + 1.1036\ (0.2621) \\
&= 2.1970 \\
\text{or}\quad a &= 157.4
\end{aligned}
$$

The empirical equation is, then,

$$y = 157.4\ x^{-0.2621}$$

and the agreement between values of y calculated from this equation and the observed values is shown in Table II.

## Type No. 3 $\quad y = a\ x^b + c$

Some data plot as a slightly curved line on logarithmic paper and are obviously not amenable to treatment by Type No. 2. In such cases it may be found that a plot of log (y — c) vs log x rather than log y vs log x will result in a straight line. Consider the data of Joos, *Combustion,* 2, No. 12, 38, 1931, on the relation between the percentage moisture, M, in steam and the rate of steam generation, R, in pounds per hour per cubic foot of steam space:

TABLE III

| M (Obsd.) | R | M—0.048 | log (M—0.048) | log R | M (Calcd.) | Per cent deviation |
|---|---|---|---|---|---|---|
| 0.10 | 250 | 0.052 | —1.2840* | 2.3979 | 0.102 | 2.0 |
| 0.28 | 500 | 0.232 | —0.6345 | 2.6990 | 0.273 | —2.5 |
| 0.80 | 900 | 0.752 | —0.1238 | 2.9542 | 0.808 | 1.0 |
| 1.38 | 1200 | 1.332 | 0.1245 | 3.0792 | 1.426 | 3.3 |
| 2.56 | 1600 | 2.512 | 0.4000 | 3.2041 | 2.552 | —0.3 |
| 4.10 | 2000 | 4.052 | 0.6077 | 3.3010 | 4.020 | —2.0 |

Fig. 3a suggests a parabolic type of curve and the plotting of M vs R on logarithmic paper. Such a plot, Fig. 3b, shows a slight, but unmistakable, curvature. If, however, a certain value, c, be subtracted from M the curve becomes a straight line since the subtraction will diminish the logarithm of M but little when M is large but will diminish log M considerably when M is small. The value, c, to be subtracted can be determined by trial and error methods but is best found as follows. Draw a smooth curve through the plotted points as in Fig. 3a and choose two points on the curve near the extremities. The chosen points may or may not correspond to the data although in this case they do since we are choosing the points (R = 250, M = 0.10) and (R = 2000, M = 4.10). Proceeding as directed under Type No. 3 in the tabulation of rectifying functions we calculate $R_3 = \sqrt{R_1 R_2} = \sqrt{250 \times 2000} = 707$ and read the corresponding value of $M_3$ from Fig. 3a as 0.507. Substituting in the equation

$$c = \frac{M_1 M_2 - M_3^2}{M_1 + M_2 - 2 M_3} = \frac{(0.10)(4.10) - (0.507)^2}{0.10 + 4.10 - 2\ (0.507)} =$$

0.048. As shown in Table III, 0.048 is subtracted from each value of M and the logarithms of (M — 0.048) and R are taken. The variables are related by the expression

$$M - 0.048 = a\ R^b$$

the logarithmic form of which is

$$\log (M - 0.048) = b \log R + \log a$$

substituting the logarithmic data into this latter form we arrive at six equations as follow:

$$
\begin{aligned}
-1.2840 &= 2.3979\ b + \log a \\
-0.6345 &= 2.6990\ b + \log a \\
-0.1238 &= 2.9542\ b + \log a \\
\hline
0.1245 &= 3.0792\ b + \log a \\
0.4000 &= 3.2041\ b + \log a \\
0.6077 &= 3.3010\ b + \log a
\end{aligned}
$$

Adding the first three and the last three equations,

$$
\begin{aligned}
-2.0423 &= 8.0511\ b + 3 \log a \\
1.1322 &= 9.5843\ b + 3 \log a
\end{aligned}
$$

Solving simultaneously,

$$
\begin{aligned}
b &= 2.071 \\
\log a &= -6.2374 \\
a &= 5.789 \times 10^{-7}
\end{aligned}
$$

and the empirical equation becomes,

$$M = 5.79\ R^{2.071} \times 10^{-7} + 0.048$$

## Types No. 4 and 5

Examples of Types No. 4 and 5 are familiar enough to the chemist but occur infrequently in power plant engineering. Type No. 4, however, occasionally enters in connection with Type No. 9 and will be discussed later, while Type No. 5 may be dismissed with the statement of the rectifying function as given in the first tabulation.

## Type No. 6 $\quad y = a + b\,x + c\,x^2$

Parabolic equations of this type are very useful and are sometimes to be preferred to those of Types No. 2 and 3. Fig. 6 and Table VI present the data of Rummel, Ind. Eng. Chem. Anal. Ed. *3,* No. 3, 317, 1931, on the effect of carbon dioxide content, W, parts per million, on the conductivity of steam condensate, C, mhos/cm. $\times\ 10^6$ at 77 deg. fahr.

* Sometimes written as 8.7160 — 10 or 2.7160.

TABLE VI

| W (Obsd.) | C | W—0.77 | C—0.50 | $\frac{W-0.77}{C-0.50}$ | W (Calcd.) | Per cent deviation |
|---|---|---|---|---|---|---|
| 0.77 | 0.50 | 0.00 | 0.00 | .... | 0.77 | 0.0 |
| 3.05 | 1.50 | 2.28 | 1.00 | 2.280 | 3.07 | 0.7 |
| 5.45 | 2.25 | 4.68 | 1.75 | 2.674 | 5.43 | —0.4 |
| 8.37 | 3.00 | 7.60 | 2.50 | 3.040 | 8.33 | —0.5 |
| 11.80 | 3.75 | 11.03 | 3.25 | 3.394 | 11.77 | —0.3 |
| 15.80 | 4.50 | 15.03 | 4.00 | 3.757 | 15.74 | —0.4 |
| 20.20 | 5.25 | 19.43 | 4.75 | 4.090 | 20.26 | 0.3 |

W is plotted against C on ordinary coordinate paper and a smooth curve is drawn through the points. A point on the curve, which may or may not be one of the plotted points, is chosen and the coordinates of this point are substituted for $x_1$ and $y_1$ in the expression, $\frac{W - W_1}{C - C_1}$, values of this expression are calculated for each plotted point and are plotted against C, as is also shown in Fig. 6. The curve is thus rectified into a straight line and we are ready to determine the constants, a and b, in the equation,

$$\frac{W - W_1}{C - C_1} = a + b\,C$$

Choosing the point ($C_1$ = 0.50, $W_1$ = 0.77), calculating (W — 0.77), (C — 0.50) and $\frac{W - 0.77}{C - 0.50}$ it is possible to set up the following equations:

$$\begin{aligned} 2.280 &= a + 1.50\,C \\ 2.674 &= a + 2.25\,C \\ 3.040 &= a + 3.00\,C \end{aligned}$$

$$\begin{aligned} 3.394 &= a + 3.75\,C \\ 3.757 &= a + 4.50\,C \\ 4.090 &= a + 5.25\,C \end{aligned}$$

Adding the first three and the last three equations we have,

$$\begin{aligned} 7.994 &= 3\,a + 6.75\,b \\ 11.241 &= 3\,a + 13.50\,b \end{aligned}$$

which yield, upon simultaneous solution, a = 1.582 and b = 0.481, so that the equation becomes

$$\frac{W - 0.77}{C - 0.50} = 1.582 + 0.481\,C$$

or, on cross multiplication,

$$W = 0.481\,C^2 + 1.34\,C - 0.02$$

Type No. 7 $\qquad y = \frac{x}{a + b\,x}$

Data which plot in the form of an equilateral hyperbola are quite common and may quickly be identified by noting that the reciprocal of y is linear with respect to the reciprocal of x. The data of Straub, *Combustion, 3*, No. 10, 12, 1932, on the solubility of calcium sulphate are a case in point. In Table VII and Fig. 7, S represents the solubility in millimoles of calcium at temperatures of t deg. fahr.

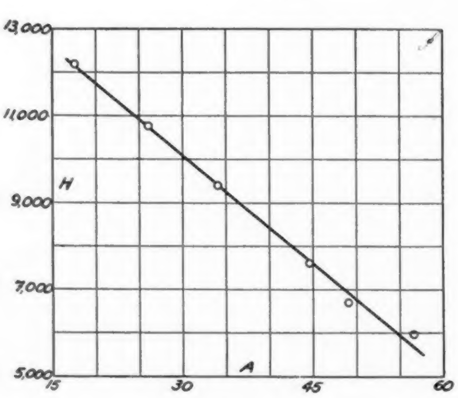


FIG. I

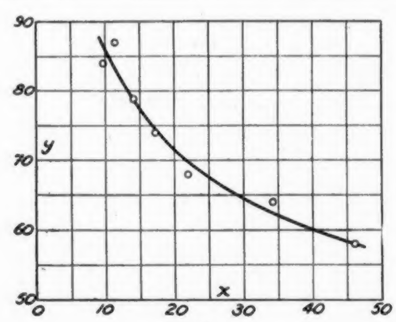


FIG. 2A

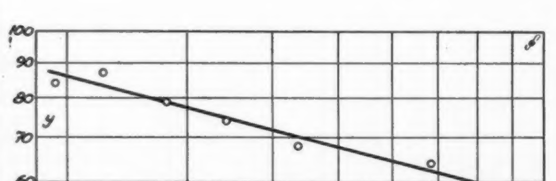


FIG. 2B

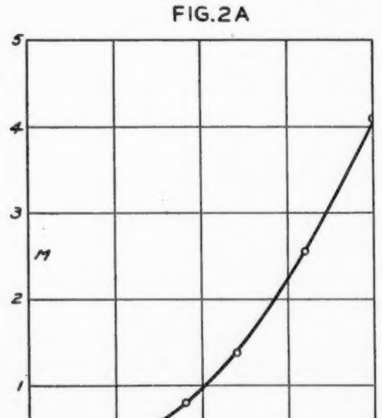


FIG. 3A

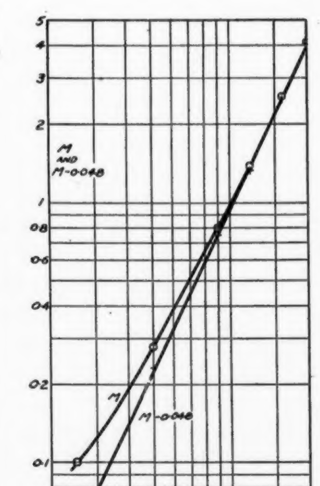


FIG. 3B

TABLE VII

| S (Obsd.) | t | $\frac{1}{S}$ | $\frac{1}{t}$ | S (Calcd.) | Per cent deviation |
|---|---|---|---|---|---|
| 0.586 | 404 | 1.706 | 0.002475 | 0.568 | —3.1 |
| 0.358 | 470 | 2.793 | 0.002128 | 0.365 | 2.0 |
| 0.292 | 539 | 3.425 | 0.001855 | 0.285 | —2.4 |
| 0.243 | 600 | 4.115 | 0.001667 | 0.248 | 2.1 |

A plot of S vs t, Fig. 7, suggests the hyperbolic nature of the data and on plotting the reciprocals of the variables it is seen that the points lie along a straight line, verifying the assumption as to the hyperbolic character of the equation. The equation of the straight line is

$$\frac{1}{S} = \frac{a}{t} + b$$

and, on substitution of data from Table VII into this form, we have

$$\begin{aligned} 1.706 &= b + 0.002475\ a \\ 2.793 &= b + 0.002128\ a \\ \\ 3.425 &= b + 0.001855\ a \\ 4.115 &= b + 0.001667\ a \end{aligned}$$

Adding the first two and the last two equations,

$$\begin{aligned} 4.499 &= 2\ b + 0.004603\ a \\ 7.540 &= 2\ b + 0.003522\ a \end{aligned}$$

which yield, upon simultaneous solution, b = 8.726 and a + —2814 so that the equation becomes

$$\frac{1}{S} = 8.726 - \frac{2814}{t}$$

or, on solving for S,

$$S = \frac{t}{8.726\ t - 2814}$$

Type No. 8 $\qquad y = \dfrac{x - x_1}{a + b\,x} + y_1$

Some data are hyperbolic in character but require additional constants in the equation. Consider the data of Brown, *Combustion, 3,* No. 10, 38, 1932, on the relation between C, the weight in pounds of the total products of combustion per pound of coal, and p, the percentage of $CO_2$ in the flue gas:

TABLE VIII

| C (Obsd.) | p | p — 12 | C — 16.95 | $\frac{p - 12}{C - 16.95}$ | C (Calcd.) | Per cent deviation |
|---|---|---|---|---|---|---|
| 16.95 | 12 | 0 | 0.00 | ...... | 16.95 | 0.0 |
| 15.70 | 13 | 1 | —1.25 | —0.800 | 15.69 | —0.1 |
| 14.63 | 14 | 2 | —2.32 | —0.862 | 14.63 | 0.0 |
| 13.70 | 15 | 3 | —3.25 | —0.923 | 13.71 | 0.1 |
| 12.92 | 16 | 4 | —4.03 | —0.993 | 12.91 | —0.1 |
| 12.18 | 17 | 5 | —4.77 | —1.048 | 12.21 | 0.2 |
| 11.61 | 18 | 6 | —5.34 | —1.124 | 11.58 | —0.2 |

C is plotted against p on ordinary coordinate paper, as in Fig. 8, and a smooth curve is drawn through the points. The coordinates of any point ($p_1$, $C_1$) on the curve are substituted in the expression, $\frac{p - p_1}{C - C_1}$, values of this expression are calculated for each plotted point and are then plotted against p, as is also shown in Fig. 8. The curve is thus rectified into a straight line, the equation of which is $\frac{p - p_1}{C - C_1} = a + b\,p$, justifying the choice of type form, and we are ready to determine the constants in the equation,

$$C = \frac{p - p_1}{a + b\,p} + C_1$$

Choosing the point ($p_1 = 12$, $C_1 = 16.95$), calculating (p — 12), (C — 16.95), $\frac{p - 12}{C - 16.95}$, and substituting in the equation, $\frac{p - 12}{C - 16.95} = a + b\,p$, it is possible to set up the six equations,

$$\begin{aligned} -0.800 &= a + 13\ b \\ -0.862 &= a + 14\ b \\ -0.923 &= a + 15\ b \\ \\ -0.993 &= a + 16\ b \\ -1.048 &= a + 17\ b \\ -1.124 &= a + 18\ b \end{aligned}$$

Adding the first three and the last three equations we have,

$$\begin{aligned} -2.585 &= 3\ a + 42\ b \\ -3.165 &= 3\ a + 51\ b \end{aligned}$$

which, upon simultaneous solution, yield a = 0.040 and b = —0.0644, so that the equation becomes

$$C = \frac{p - 12}{0.040 - 0.0644\ p} + 16.95$$

Type 9 $\qquad y = a + b\,x = (10)^{c + d\,x}$

In many cases a considerable portion of the data plots as a straight line while the remainder shows a distinct curvature. While it is possible to divide the data into two ranges and to devise equations of differing types for each, it is more convenient to represent the data by an equation which can be used over the entire range. Part of such an equation is of the form of Type No. 1 and dominates the linear portion of the curve while the other part is of a nature such that it does not appreciably affect the linear part but does throw the straight line into a curve outside this range. This latter part of the equation is frequently of the form of Type No. 4 and is represented by the last term in the equation,

$$y = a + b\,x + (10)^{c + d\,x}$$

The data of Joos, *Combustion,* 2, No. 12, 38, 1931, on the relation between the reduction, R deg. fahr., in superheat due to the presence of one per cent of moisture, and the absolute pressure, P, in pounds per square inch, are an excellent case in point:

TABLE IX

| R (Obsd.) | P | R′ | $\delta = R - R'$ | log $\delta$ | $\delta$ (Calculated) | R (Calculated) | Per cent deviation |
|---|---|---|---|---|---|---|---|
| 15.22 | 500 | | | | 0.002 | 15.22 | 0.0 |
| 15.45 | 450 | | | | 0.004 | 15.47 | 0.1 |
| 15.70 | 400 | | | | 0.008 | 15.72 | 0.1 |
| 15.95 | 350 | | | | 0.016 | 15.97 | 0.1 |
| 16.37 | 275 | 16.32 | 0.05 | —1.3010 | 0.048 | 16.37 | 0.0 |
| 16.83 | 200 | 16.69 | 0.14 | —0.8539 | 0.145 | 16.84 | 0.1 |
| 17.50 | 125 | 17.06 | 0.44 | —0.3565 | 0.440 | 17.50 | 0.0 |

A plot of the data, Fig. 9a, is a curve below P = 350 and a straight line above this value. For the linear portion let

$$R' = a + b\,P$$

and substitute the data in this equation, obtaining the four equations,

$$15.22 = a + 500\,b$$
$$15.45 = a + 450\,b$$

$$15.70 = a + 400\,b$$
$$15.95 = a + 350\,b$$

Adding the first two equations and the last two we have,

$$30.67 = 2\,a + 950\,b$$
$$31.65 = 2\,a + 750\,b$$

which, upon simultaneous solution, yield a = 17.67 and b = —0.0049 so that the equation becomes

$$R' = 17.67 - 0.0049\,P$$

Upon solving this equation for R′ when values of P are 275, 200, and 125, respectively, we have the values in the R′-column of Table IX corresponding to the dotted line in Fig. 9a. R′ differs from R by the amount, $\delta$, which appears in the fourth column of the table. Fig. 9b, a plot of $\delta$ vs P on semi-logarithmic paper, which amounts to plotting log $\delta$ vs P on ordinary coordinate paper, shows a linear relationship between log $\delta$ and P, so that

$$\log \delta = c + d\,P$$

which is the logarithmic form of the equation,

$$\delta = (10)^{c+dP}$$

When values of log $\delta$ and P are substituted in the logarithmic equation we obtain the following:

$$-1.3010 = c + 275\,d$$
$$-0.8539 = c + 200\,d$$

$$-0.3565 = c + 125\,d$$

Adding the first two equations, we have,

$$-2.1549 = 2\,c + 475\,d$$

which, upon simultaneous solution with the third, yields c = 0.4448 and d = —0.00641 so that the equation becomes

$$\delta = (10)^{0.4448 - 0.00641\,P}$$

Since R = R′ + $\delta$, we have, on substitution,

$$R = 17.67 - 0.0049\,P + (10)^{0.4448 - 0.00641\,P}$$

Inspection of the column headed "$\delta$ (Calcd.)"

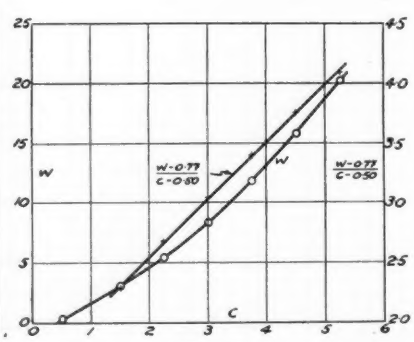

FIG. 6

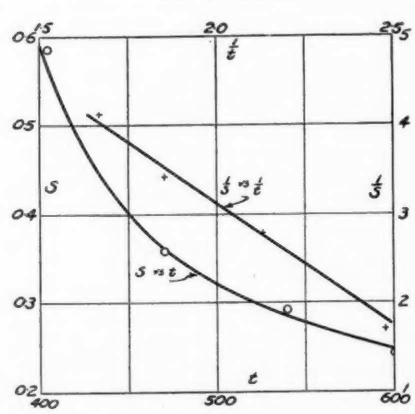

FIG. 7

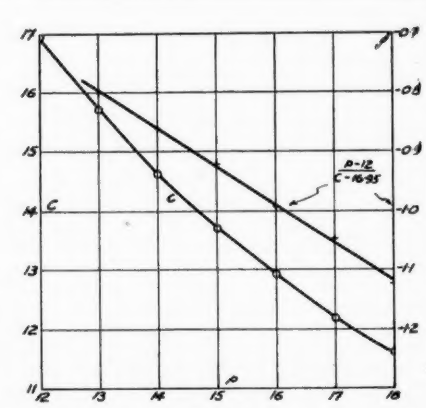

FIG. 8

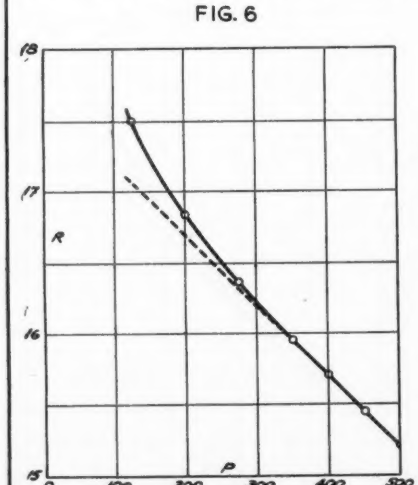

FIG. 9A

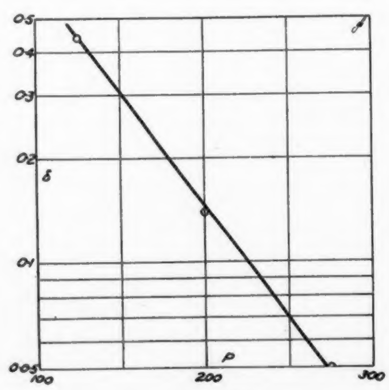

FIG. 9B

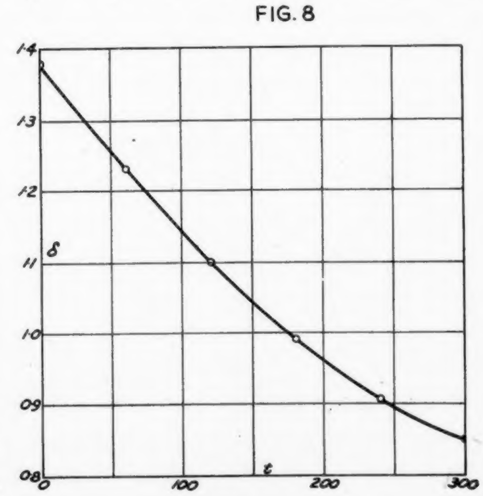

FIG. 10

shows that the $\delta$-part of the equation leads to negligible values above P = 350 and so does not affect the linear portion of the curve but that below P = 350 the $\delta$-term becomes large enough to throw the straight line into a curve.

Type No. 10 $$y = a + bx + cx^2 + dx^3$$

When other types of equation are found unsuitable, resort can usually be made to the polynomial form of Type No. 10 although it involves somewhat more labor in determining the constants. Consider the data of Wilson, McAdams, and Selzer quoted in "Petroleum Products Engineering," McGraw-Hill, p. 439, on the specific gravity of dry air at various temperatures. $\delta$ indicates 100 times the specific gravity of dry air relative to water at 39 deg. fahr., where t is the fahrenheit temperature.

TABLE X

| $\delta$ (Obsd.) | t | $\delta$ (Calcd.) | Per cent deviation |
|---|---|---|---|
| 1.380 | 0 | 1.380 | 0.0 |
| 1.230 | 60 | 1.231 | 0.1 |
| 1.100 | 120 | 1.100 | 0.0 |
| 0.990 | 180 | 0.991 | 0.1 |
| 0.906 | 240 | 0.906 | 0.0 |
| 0.850 | 300 | 0.850 | 0.0 |

By substitution of the coordinates of four points and subsequent simultaneous solution of the four equations thus obtained the equation may be made to represent any four points exactly. On plotting the data as in Fig. 10 it is seen that, of the six points, the 0, 120, 240, and 300 degree data are a wise choice since they embody both the flat and curved portions of the plot. The following equations are then set up,

$$\begin{aligned}
1.380 &= a + (0)\,b + (0)^2\,c + (0)^3\,d \\
1.100 &= a + 120\,b + (120)^2\,c + (120)^3\,d \\
0.906 &= a + 240\,b + (240)^2\,c + (240)^3\,d \\
0.850 &= a + 300\,b + (300)^2\,c + (300)^3\,d
\end{aligned}$$

These, upon simultaneous solution, yield

$$a = 1.380,\quad b = -2.61 \times 10^{-3},\quad c = 2.01 \times 10^{-6}, \text{ and } d = 2.70 \times 10^{-9}$$

so that the equation becomes

$$\delta = 1.380 - 2.61\,t \times 10^{-3} + 2.01\,t^2 \times 10^{-6} + 2.70\,t^3 \times 10^{-9}$$

In instances where none of the ten types of equation fits the data in their entirety it is generally possible to split the data into two or three ranges and to fit differing forms of equation to each. In still more difficult cases curve-fitting may become a matter of seeking rectifying functions of any nature whatever as long as the ultimate end is attained.

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**R. J. Bender,** formerly with the Whiting Corporation, Pulverizing & Combustion Division, has become identified with the Sales Department of the Sinclair Refining Company as Combustion Engineer. In his new office Mr. Bender will give technical advice and service to the users of Sinclair fuel oil in both domestic and industrial fields.

# Boiler, Stoker and Pulverized Fuel Equipment Sales

***As reported by equipment manufacturers to the Department of Commerce, Bureau of the Census.***

## Boiler Sales

Orders for 323 boilers were placed in June by 72 manufacturers

| | Number | Square feet |
|---|---|---|
| June, 1932 | 323 | 316,662 |
| June, 1931 | 776 | 633,504 |
| January to June (inclusive, 1932) | 1,542 | 1,617,609 |
| Equivalent period, 1931 | 3,591 | 3,341,536 |
| Total, 1931 | 7,508 | 6,327,262 |

NEW ORDERS, BY KIND, PLACED IN JUNE, 1931-1932

| | June, 1931 | | June, 1932 | |
|---|---|---|---|---|
| Kind | Number | Square feet | Number | Square feet |
| Stationary: | | | | |
| Water tube | 88 | 308,360 | 42 | 157,732 |
| Horizontal return tubular | 57 | 77,751 | 19 | 35,397 |
| Vertical fire tube | 54 | 12,047 | 25 | 6,309 |
| Locomotive, not railway | 11 | 9,224 | 2 | 1,163 |
| Steel heating | 534 | 205,441 | 216 | 102,788 |
| Oil country | .... | ...... | .... | ...... |
| Self contained portable | 24 | 17,262 | 19 | 13,273 |
| Miscellaneous | 8 | 3,419 | .... | ...... |
| Total | 776 | 633,504 | 323 | 316,662 |

## Mechanical Stoker Sales

Orders for 113 stokers totaling 25,096 hp. were placed in June by 55 manufacturers

| | Installed under | | | |
|---|---|---|---|---|
| | Fire-tube boilers | | Water-tube boilers | |
| | No. | Horsepower | No. | Horsepower |
| June, 1932 | 65 | 8,751 | 48 | 16,345 |
| June, 1931 | 149 | 19,455 | 63 | 22,720 |
| January to June (inclusive, 1932) | 379 | 50,963 | 187 | 79,176 |
| Equivalent period, 1931 | 629 | 82,394 | 282 | 100,877 |
| Total, 1931 | 1,889 | 252,571 | 574 | 187,507 |

## Pulverized Fuel Equipment Sales

Orders for 16 pulverizers with a total capacity of 49,100 lb. per hr. were placed in June

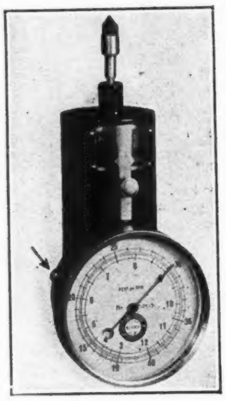
| | STORAGE SYSTEM | | | | | | |
|---|---|---|---|---|---|---|---|
| | Pulverizers | | | | Water-tube Boilers | | |
| | Total Number | No. for new boilers, furnaces and kilns | No. for existing boilers | Total capacity lb. coal per hour for contract | Number | Total sq. ft. steam generating surface | Total lb. steam per hour equivalent |
| June, 1932 | .. | .. | .. | ...... | .. | ...... | ....... |
| June, 1931 | .. | .. | .. | ...... | .. | ...... | ....... |
| January to June (inclusive, 1932) | .. | .. | .. | ...... | .. | ...... | ....... |
| Equivalent period, 1931 | 7 | 6 | 1 | 220,000 | 3 | 114,577 | 1,671,000 |
| Total, 1931 | 8 | 7 | 1 | 250,000 | 37 | 126,471 | 1,797,000 |
| | DIRECT FIRED OR UNIT SYSTEM | | | | | | |
| | Pulverizers | | | | Water-tube Boilers | | |
| June, 1932 | 12 | 5 | 7 | 44,850 | 13 | 47,980 | 356,000 |
| June, 1931 | 14 | 6 | 8 | 59,360 | 11 | 56,080 | 530,290 |
| January to June (inclusive, 1932) | 40 | 27 | 13 | 207,338 | 36 | 199,086 | 1,868,450 |
| Equivalent period, 1931 | 46 | 33 | 13 | 279,110 | 35 | 246,880 | 2,960,165 |
| Total 1931 | 72 | 52 | 20 | 450,960 | 58 | 417,327 | 4,455,585 |
| | | | | | Fire-tube Boilers | | |
| June, 1932 | 4 | 1 | 3 | 4,250 | 4 | 5,500 | 37,250 |
| June, 1931 | 4 | 1 | 3 | 4,000 | 4 | 5,750 | 22,100 |
| January to June (inclusive, 1932) | 12 | 1 | 11 | 12,300 | 12 | 19,000 | 108,750 |
| Equivalent period, 1931 | 19 | 3 | 16 | 22,800 | 19 | 31,954 | 192,300 |
| Total, 1931 | 35 | 11 | 24 | 39,300 | 37 | 59,761 | 347,100 |

# NEW EQUIPMENT

**of interest to steam plant Engineers**

### Hand Tachometer

The Amthor Testing Instrument Company, 309 Johnson St., Brooklyn, N. Y., has developed the Amthor type No. 350 direct-reading Hand Tachometer. This instrument features automatic fixed reading, whereby the speed reading is

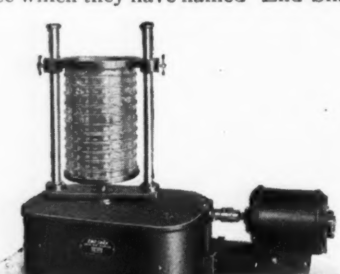


automatically fixed on the dial after each time the instrument is used. This tachometer may be used in the dark, if necessary, or in places where it is awkward to hold and read at the same time because of this new feature.

The dial is graduated to read directly in r.p.m. but the instrument is equipped with accessories so that "ft. per min." surface and belt speeds can be taken. The tachometer has four speed ranges, each of which is separately read over the entire circumference of the dial to give greater graduation space and consequently closer readings. Each is constructed with a finely balanced cross-pendulum governor movement, is hand calibrated for accuracy, and is dead beat in action. Speeds up to 12,000 r.p.m. can be directly measured.

### Automatic Sieve Shaker

The Newark Wire Cloth Company, Newark, New Jersey have recently developed a mechanical testing sieve shaker device which they have named "End-Shak."



The "End-Shak" weighs 275 lb. including the motor and auto time switch. The base, overall is 33 in. by 13 in. A standard ¼ hp. motor is used—110 and 220 volt, 60 cycle alternating current, 1750 r.p.m. Belt drive or special motor equipment is optional. The standard auto time switch automatically controls the period of the test. "End-Shak" is designed for 8 in. dia. testing sieves, and may hold from 1 to 13 sieves.

The following features are claimed: 1. elimination of most of the variable factors in sieve testing, 2. laboratory and plant results are brought into closer relationship as, a. sample is spread uniformly over the entire surface of the sieve, b. jumping and bouncing of the sample particles eliminated, c. wear and tear on parts minimized and d. operation is smooth and easy.

### Midwest Shaped Welding Nipples

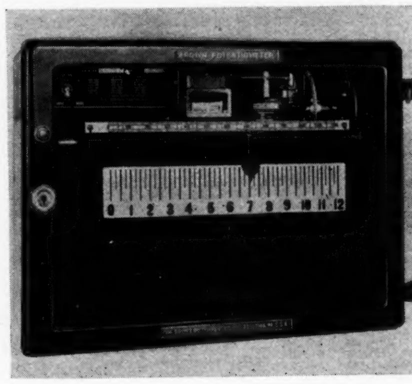
The Midwest Piping & Supply Company, Inc., of St. Louis, Missouri, has recently placed on the market a line of Midwest Shaped Welding Nipples which eliminate templates when saddling one pipe upon another. The nipple is placed in position before the opening is cut in the pipe upon which it is to be saddled;


the correct opening is then traced from the nipple contact line. As a result, the Midwest Welding Nipple assures an accurate fit. Both the shaped end and the square end are beveled for welding.

Midwest Shaped Nipples (both 90 deg. and 45 deg.) are regularly made from standard weight and extra heavy wrought steel pipe and genuine wrought iron pipe; sizes are from 1¼ in. to 12 in. inclusively.

### Self-Balancing Indicating Potentiometer

A new indicating potentiometer of the self-balancing type is the latest addition to the potentiometer line of the Brown Instrument Company, Philadelphia, Pa. This is an advance in potentiometer design since most indicating potentiometers hitherto have required hand balancing. Aside from this main design feature, many other advantages are claimed for the new Brown Indicating Potentiometer. Among these are a long (40-in.) slide wire, positive spiral shaft drive, a non-slip clutch, a secondary pointer definitely fixing the size of step



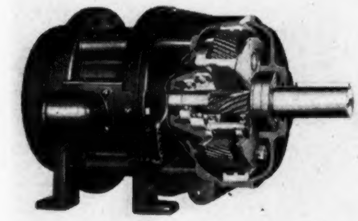
in moving the slide wire contact, interchangeable case for universal mounting, mechanism swings out of case for easy inspection without interference with operation, mercury-in-glass switches in control models and automatic thermal equalization between cold junction terminals and compensation coil.

This potentiometer has a scale with large figures, calibration marks and pointer; making accurate reading easy at a considerable distance. As a pyrometer this instrument can be supplied for any range from 0 to 100 deg. fahr. up to 0 to 3000 deg. fahr. or for almost any span between these ranges.

### New Gear-Motors

A line of gear-motors, readily adaptable for application to machinery of widely various designs, has been announced by the General Electric Company. The underlying principle of these gear-motors consists of a normal speed motor in combination with a built-in internal-helical planetary-gear speed-reducer. Since this type of construction permits a wide choice of speeds on the output shaft, it is possible to adapt a gear-motor to almost every type of low-speed drive. Compact construction, high efficiency, full horsepower rating of the motor at the output shaft, and simple design are some of the many features of these gear-motors.

Gear-motors are also offered with special electrical characteristics, such as high starting torque with low starting current, normal starting torque with low



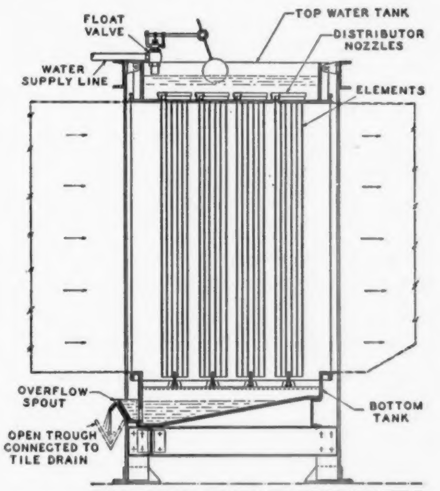
starting current, adjustable, varying speed, multispeed, etc., or mechanical features such as totally enclosed; totally enclosed, fan-cooled; or Class I. Group

D, construction for use in hazardous gas locations.

Alternating current, polyphase, squirrel-cage and wound-rotor gear-motors are available in ratings up to 75 hp., single phase to 5 hp., and d.c. to 7½ hp. Direct current gear-motors are offered for those applications where either the advantages of adjustable speed drive or a d.c. source of supply render their use desirable. Standard gear-motors can be had with shaft speeds down to 13 r.p.m.

## Flue Gas Scrubber

Due to the enactment of more rigid air pollution ordinances and more rigid enforcement of these ordinances, atmospheric pollution has become of primary importance to everyone whose business requires the operation of power or process equipment or other equipment, the atmospheric discharge from which produces smoke, fly ash, cinders or chemical pollution of the atmosphere.




Many plants have been seriously embarrassed because of the violation of existing ordinances. The Riley Flue Gas Scrubber was developed by the Riley Stoker Corp., Worcester, Mass., and is now available to prevent air polution.

The Riley Flue Gas Scrubber consists of a series of ribbed baffle plates placed vertically between two tanks. The gases which are to be cleaned pass through the scrubber horizontally. The baffle plates are placed at an angle to the direction of flow of gases and are so arranged as to cause the gases to successively impinge against the surfaces of the plates. Water from the upper tank of the scrubber is distributed over the faces of the baffle plates by distributing nozzles at the top of each of the plates.

The gases passing through the scrubber zig zag paths impinge against the wet surfaces of the baffle plates. These wet surfaces arrest the dust particles and soluble gases. The film of water flowing continuously over the surface of the baffle plates carries these impurities to the lower collecting tank. This settling tank is sufficiently large to hold several minutes' discharge of water from the scrubber. The overflow from this tank is discharged into a drain.

The design of Riley Flue Gas Scrubbers is based on the principle of removing dust from flue gases by means of multiple films of water against which the flue gases must successively impinge during their travel through the scrubber. The use of films of water instead of sprays tremendously decreases the surface of the water exposed to the flue gases and consequently the quantity of water evaporated and carried out of the stack by the gases is greatly reduced. Also as the flue gases do not pass through the films of water but merely impinge against the films of water, there is no tendency for the gases to carry away large quantities of entrained moisture. With the Riley Scrubber less than 4 per cent of the water fed to the scrubber is evaporated and picked up by the gases whereas with the spray principle as high as 25 per cent of the water may be lost through evaporation. Consequently, with the Riley Scrubber the dew point of the gases leaving the scrubber is not seriously affected.

It is claimed that because of the effectiveness of the films of water in removing the dust from the flue gases, the size of the scrubbers to take care of a given steam output or in other words a given quantity of flue gas is comparatively small, making possible their installation under restricted space conditions and at reasonable investment cost

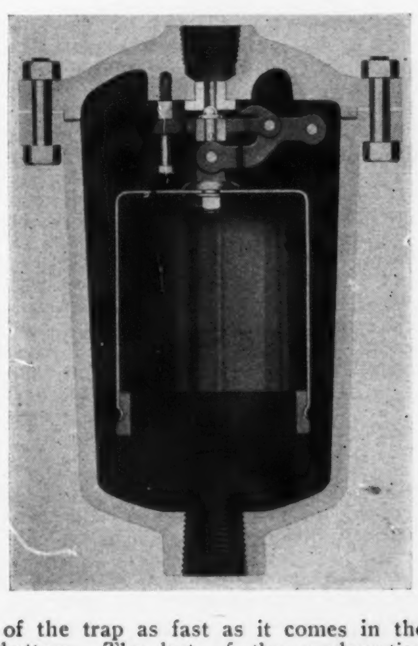
## Inverted Bucket Trap

The Swartwout Company, 18511 Euclid Avenue, Cleveland, Ohio, announces the New Swartwout Type "A" Inverted Bucket Trap.

The body of a Swartwout Type A inverted bucket trap in operation is substantially full of water at all times. When the upper part of the bucket is partly full of steam and air the bucket floats and keeps the valve closed.

Air escapes through the small vent in the top of the bucket, and collects in the top of the trap, ready to go out at the next discharge. Steam also escapes through the same vent, condensing in the water above the bucket. As water replaces this air and steam in the bucket, the bucket loses its buoyancy and opens the valve.

As long as condensation continues to come into the bottom of the trap, the bucket remains down and the valve open, the water going out of the top



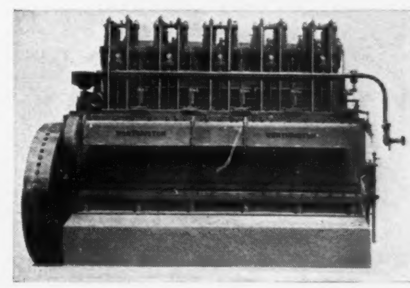
of the trap as fast as it comes in the bottom. The last of the condensation entering the trap is followed by steam and air, which fills the bucket by displacing the water. Thereupon the bucket rises and closes the valve and the cycle of operation is repeated.

## Diesels

Covering power requirements from 50 to 1000 hp., in two or eight cylinder units, a line of four-cycle direct injection moderate speed Diesel engines for stationary and marine services, recently has been introduced by the Worthington Pump and Machinery Corporation, Harrison, N. J.

These Diesels have individual fuel pumps for each cylinder which hydraulically control the injection of fuel lines of equal length, individual air starting pilot valves to control the admission of starting air to each cylinder and pressure-actuated spray valves. In the larger engines, air inlet and exhaust valves are carried in removable and interchangeable cages, the exhaust valve cages being water cooled; in the smaller engines, these valves (also interchangeable and adjustable) seat directly in the cylinder head and operate in removable bushings.

Lubricating oil is circulated, through a cast-in main duct in the base with cast-in branches leading to the bottom of each main bearing, by an attached pump. From the main bearings, the oil reaches the crank and wrist-pin bear-



ings under pressure through drilled passages in the crankshaft and connecting rods. Other points requiring lubrication —camshaft gear, governor, etc.—are supplied with oil under pressure from the flywheel and of the main oil duct. In all but the smallest engines, the cylinders are two-point lubricated by force-feed.

The camshaft, readily removable at right angles, is driven by spur gears with silent spiral teeth from the flywheel end of the engine. The entire camshaft assembly, including its lubrication, is inclosed with a tight cover. Cooling is provided at all essential points, including the exhaust manifold, the principal feature being that the flow in all jackets is so directed that high water velocities result and there are no dead pockets. Large handholes permit ready cleaning of the jackets of both cylinder liners and heads, and large doors in front and rear give unobstructed access to main and crank bearings.

These Diesels can be easily converted to operation on manufactured or natural gas—the same base, frame, crankshaft and connecting rod being used for both engines. The camshaft is the same except that the fuel cams are omitted or not used if the engines are to operate on gas. When running on gas, a magneto and spark plugs replace fuel pumps and spray valves; a mixing valve is bolted to the end of the regular inlet manifold; and gas engine cylinders, with larger valves in the heads, are substituted.

# NEW CATALOGS AND BULLETINS

**Any of the following publications will be sent to you upon request. Address your request direct to the manufacturer and mention COMBUSTION Magazine**

### Cranes

A book has been just published entitled "Overhead Handling at Low Cost" describing Whiting Cranes. These cranes are built in capacities ranging from 3 to 350 tons and are adapted to power plant, railroad, foundry and general industrial work. The Whiting Crane design and construction are gone into in great detail. Many photographs of installations of various types are shown. Tables giving various data are also included. 68 pages and cover, 8½ x 11—Whiting Corporation, Harvey, Illinois.

### Expansion Joints

A new illustrated bulletin No. 40-A describes in detail the "Flexodisc" packless expansion joint suitable for providing expansion in steam mains, miscellaneous piping and for special expansion problems, available in sizes from 3 in. to 30 in. expansion element of alloy steel. 8 pages, 8½ x 11—Croll-Reynolds Engineering Company, Inc., 17 John Street, New York.

### Fans

A new catalog has just been issued describing Buffalo Limit Load Conoidal Fans. These fans have fixed inlet vanes which are claimed to materially reduce noise and increase the efficiency. The vanes also provide an effective safety guard without the obstruction to air flow encountered with a screen. The outlet extends out beyond the scroll lines of the housings a sufficient distance to provide a proper cut-off and tangential flare from tip of wheel to the lower side of outlet, thus reducing turbulence and noise. 8 pages, 8½ x 11—Buffalo Forge Company, Buffalo, New York.

### Feed Water Regulator

A pamphlet has been recently published describing the new Copes Type DA Feed Water Regulator. This regulator is simply a disk valve actuated by an expansion tube or thermostat. This tube is in tension, eliminating any chance for compression strain. The features claimed are as follows:—Easily installed, results are good whether the installation is made indoors or outdoors, fully automatic, will hold the water level constant. 4 pages, 8½ x 11—Northern Equipment Company, Erie, Pa.

### Gaskets

A pamphlet has recently been issued describing the design and construction of Kell-Raph Copper Plated Gaskets for high pressure, high temperature pipe joints. This gasket consists of a steel core, plated with a copper coating which is applied by a special process assuring uniform thickness. Gaskets to be applied to Van Stone joints have a device attached to them which automatically centers them in the joint. 4 pages, 8½ x 11—The M. W. Kellogg Company, 225 Broadway, New York, N. Y.

### Small Stoker Unit

A pamphlet has just been issued illustrating and describing the design, construction and operating features of the new Type E Stoker-Unit. This stoker is a small replica of the Type E Underfeed Stoker which was introduced to American steam practice 30 years ago. It is particularly adapted to heating and small industrial plant boilers and is built in capacities ranging from 40 to 200 developed boiler horsepower and in terms of steam radiation capacity, these developed capacities correspond to 5500 to 28,000 sq. ft. respectively. Line drawings and a table of principal dimensions are included, 4 pages, 8½ x 11—Combustion Engineering Corporation, 200 Madison Avenue, New York, N. Y.

### Stainless Steel Tubes

The Globe Stainless Tube Company, manufacturers of seamless stainless tubes, have issued the third edition to their bulletin No. 1 giving in tabulated form the various stainless steels, their trade names, manufacturers and analyses. 6 pages, 8½ x 11—Globe Stainless Tube Company, Milwaukee, Wisconsin.

### Steam Engine Savings

How six representative concerns cut power costs is the story told in a recently issued pamphlet. The surveys were purposely made in various parts of the country of various applications under different operating conditions. This was done to afford interested investigators an opportunity to grasp the extent of the savings ability of Troy-Engberg equipment. The surveys cover the following types of installations: draft fan and underfeed stoker drive, d.c. and a.c. power and light generation, chain-grate stoker drive, compressor drive and ventilating fan drive. 8 pages and cover, 8½ x 11—Troy Engine & Machine Company, Troy, Pennsylvania.

### Superheaters

A pamphlet has just been issued describing the newly designed superheater for h.r.t. boilers. This superheater comprises two cast-steel headers which are suspended one on each side of the boiler shell and are connected by detachable tubular elements or units extending around the underside of the boiler. The headers are supported by adjustable clamped steel rods. By raising or lowering the headers the units are correspondingly raised or lowered in the combustion chamber, thus regulating the superheat or final temperature of the steam. 4 pages, 8½ x 11—The Superheater Company, 60 East 42nd Street, New York, N. Y.

### Tandem Blow-Off Valve

Bulletin 693 recently published describes the new Cochrane Tandem Blow-off Valve. This valve embodies the same principles as the high-pressure tandem blow-off valve brought out by the same company about three years ago; namely, it comprises a single forged-steel body in which are combined a rotatable gate valve and a compound screw down valve. This new valve, now offered for lower pressures, has a valve body made of nickel chromium alloy cast iron for pressures up to 250 lb., and of cast steel for pressures up to 400 lb. 4 pages, 8½ x 11—Cochrane Corporation, Philadelphia, Pennsylvania.

### Temperature Controllers

Catalog No. 177 describes the design and construction of the Foxboro Temperature Controllers. This controller consists of two major units—the thermal element which is sensitive to the temperature changes and the air operated control unit, which regulates the admission of the heating or cooling medium through the controlled valve. The catalog is well illustrated and contains many tables and charts. 48 pages, 8½ x 11—The Foxboro Company, Foxboro, Mass.

### Turbine Blowers

Bulletin T-97 describes the design, construction, capacities and application of the Wing Turbine Blowers for stoker-fired or hand-fired boilers. The bulletin is profusely illustrated and also contains charts and tables. 16 pages and cover, 8½ x 11—L. J. Wing Mfg. Company, 154 West 14th Street, New York, N. Y.

## NOTICE

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# REVIEW OF NEW TECHNICAL BOOKS

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## Pulverized Fuel Firing

**By Sydney H. North**

PULVERIZED fuel, like many other important engineering developments, went through a long period of uneventful experimentation and then suddenly achieved almost universal acceptance as the most efficient of all methods of coal combustion. The earliest known inventions in this field were made as long ago as 1818, and during the remainder of the nineteenth century and the early part of the twentieth the idea flared up sporadically to hold interest for a short while and then die out again. While some apparently successful applications were made in the years from 1900 to 1915, especially in the cement and metallurgical industries, it was not until after that period that pulverized fuel, as applied to stationary boilers, really proved its case. From then on its progress throughout the world is common knowledge.

The author of this book, an Englishman, briefly reviews the history of pulverized fuel as a prelude to a discussion of its development to the present day. Contemporary designs of furnaces, burners, feeders, pulverizing mills, driers, dust collectors, etc., are described and illustrated, as are actual installations in America and Europe which exemplify the trends of practice. Chapters are devoted to the combustion of pulverized fuel and its use in connection with Lanchashire boilers, marine boilers and in metallurgical furnaces.

All in all, this book presents an up-to-date survey of pulverized fuel firing with respect to both American and European practice. As such it serves a valuable purpose, since few books on this subject have been published within the past few years, during which period improvements in equipment and progress in the art have advanced rapidly.

This book contains 204 pages, size 5 x 7½. Price $2.25.

## American Machinists' Handbook

**(Fifth Edition)**

**By Fred H. Colvin and Frank A. Stanley**

THE Fifth Edition of the *American Machinists' Handbook* needs no introduction, as this book has come to be recognized everywhere as the standard manual of data, methods and definitions for apprentices, machinists, toolmakers, draftsmen, designers, foremen, superintendents, and all others connected with machine shop work.

Constantly the authors have changed and revised it, so that page for page it represents only the most helpful and needed data in the metal-working, machinery manufacturing and allied industries.

Every section of the Fifth Edition has been thoroughly revised—some of them have been practically entirely re-written. A great deal of the new material is in the shape of data and methods which have been developed and are now being used in some of the world's leading manufacturing concerns. Another feature is in the insertion of special tables and diagrams to help in estimating and selecting proper equipment for various jobs. Obsolete material has been weeded out, making the book 100 per cent usable and up-to-date.

This flexible-bound volume, of a handy, pocket size, 4 x 7, contains 1140 pages. Price $4.00.

## Handbook of the National District Heating Association—1932

**(Second Edition)**

THIS handbook, which is essentially an encyclopedia of district heating, will be of interest and value not only to those who are actively engaged in this work but also to those who desire to familiarize themselves with this important industry.

The material contained in this book is drawn from the wealth of papers and reports in the Association's proceedings, and from the files of many operating companies which have given their generous support to this enterprise. Every effort has been made to insure that the data and ideas which are offered are authentic and well-seasoned rather than representing merely the thoughts of individuals.

The opening chapter tells of the growth of this industry from its beginning in 1877 up to the present. Other chapters present engineering data useful in the calculation of heating requirements, planning and designing of heating plants and systems. The final chapters discuss rates and sales activities of the district heating industry, and the economical use of steam. This latter chapter is probably one of the most interesting and valuable chapters of the book as it gives much detailed information covering the possibilities of reducing waste in steam.

This book, containing 538 pages, has a flexible fabrikoid binding, size 6 x 9. Price $5.00.